

FINAL REPORT FOR ENERGY- EFFICIENT, MOLD-RESISTANT MATERIALS AND CONSTRUCTION PRACTICES FOR NEW CALIFORNIA HOMES

Prepared For:

**California Energy
Commission**

Public Interest Energy Research
Program

Prepared By:

Gas Technology Institute



Arnold Schwarzenegger
Governor

PIER FINAL PROJECT REPORT

August 2008

CEC-500-2007-036

Prepared By:

Gas Technology Institute
Neil Leslie
Des Plaines, Illinois, 60018
Contract No. 500-03-013

Prepared For:

Public Interest Energy Research (PIER)
California Energy Commission

Ann Peterson, Phil Spartz

Contract Manager

Norm Bourassa

Program Area Lead

Building End-Use Energy Efficiency Program



Martha Krebs, Ph.D.

PIER Director

Thom Kelly, Ph.D.

Deputy Director

ENERGY RESEARCH & DEVELOPMENT DIVISION

Melissa Jones

Executive Director

DISCLAIMER

This report was prepared as the result of work sponsored by the California Energy Commission. It does not necessarily represent the views of the Energy Commission, its employees or the State of California. The Energy Commission, the State of California, its employees, contractors and subcontractors make no warrant, express or implied, and assume no legal liability for the information in this report; nor does any party represent that the uses of this information will not infringe upon privately owned rights. This report has not been approved or disapproved by the California Energy Commission nor has the California Energy Commission passed upon the accuracy or adequacy of the information in this report.

Acknowledgments

The products and outcomes presented in this report are a result of funding provided by the California Energy Commission's Public Interest Energy Research (PIER) Program on behalf of the citizens of California. Additional funding was provided by Gas Research Institute on behalf of gas industry ratepayers. Gas Technology Institute would like to acknowledge the support and contributions of the individuals below in the successful completion of this research project.

Project and Contract Management

Nancy Jenkins, P.E., Manager (Former), Energy Efficiency Research Office

Martha Brook, P.E., Senior Mechanical Engineer

Chris Scruton, Mechanical Engineer

Phil Spartz, Commission Contract Manager

Eric Stubee, Project Manager, SAIC

Research Team Leaders

Doug Beaman, Douglas Beaman Associates

Carl Bergstrom, Magus Consulting

Charles Eley, FAIA, P.E., Architectural Energy Corporation

Lew Harriman, CMR, Mason-Grant Consulting

Doug Kosar, Energy Resources Center, University of Illinois at Chicago

Bud Offermann, P.E., CIH, Indoor Environmental Engineering

Project Advisory Committee (PAC)

Doug Bibee, The Dow Chemical Company

Cordell Burton, The Pella Corporation

Pamela Davis, RN, PHN, California Research Bureau

Steve Easley, S.C. Easley and Associates

Barry Hardman, National Building Science Corporation

Darren Hudema, MWR, Dri-Eaz, Inc.

Claudia Lezell, Flooring Technology Institute

Don McNeill, California Department of Insurance

Jim Miyao, Sempra Energy Utilities

Frank Nunes, Lathing and Plastering Institute of Northern California

Mel Rasco, The Dow Chemical Company
Susan Raterman, CIH, The Raterman Group, Ltd.
Linda Schieffelin, Clarum Homes
Paul Shipp, Ph.D., P.E., USG Corporation
Charlene Spoor, Pacific Gas and Electric Company
Damon Tanaka, John Laing Homes
Jed Waldman, Ph.D., California Department of Health Services
David Ware, Owens Corning
Theresa Weston, Ph.D., DuPont Nonwovens

Participating Builders

Clarum Homes

John Suppes, Vice President
Operations

Linda Schieffelin, Senior Purchasing Agent

Jimmy Blackwell, Field Superintendent

John Laing Homes Inland Division

Victor Goochéy, Vice President

Damon Tanaka, Purchasing Agent

Joe Vargas, Field Superintendent

Donors of Building Materials and Engineering Support

Broan-Nutone LLC

Continuous duty exhaust fans

Terry Pond and Kevin Morris

CTL Group/Wagner Electronics

RH sensors for concrete
measurements

Scott Tarr

Degussa Construction Systems Americas

Concrete moisture evaporation
inhibitor, pocket former filler

Robert Gulyas and Nils Fox

Dow Chemical

Styrofoam sheathing, housewrap
and foam sealant

Doug Bibee, Mel Rasco, and Bob
Braun

Dri-Eaz, Inc.

Construction drying equipment

Darren Hudema

DuPont Nonwovens

Housewrap, flashings, and fasteners

Theresa Weston, Brett Lubson, and
Marc Silveira

Fortifiber Building Systems Group

Building paper and flashing

David Olson

Foster Products

Fungicidal coatings

Troy Anderson and Harry Certain

G-P Gypsum

Glass matt-faced gypsum wall board

Barry Reid

IFTI

Concrete testing services

Lee Eliseian

Owens Corning

Foam insulation and housewrap

David Ware

Pella Corporation

Windows and flashing

Cordell Burton and John Woestman

PNA Construction Technologies

Concrete curing covers

Bob Waggoner and Nigel Parkes

Stego Industries

Vapor retarder membranes

Bret Houck and Matt Blasdel

SureSill, Ltd.

Sill pans

Mishko Teodorovich

Tamarack Technologies

Exhaust fan controllers

Paul Raymer

USG Corporation

Mold resistant gypsum wall board

Paul Shipp

Additional Support

John Banta, CMR, Restcon

Mark Bomberg, Ph.D., Syracuse
University

Peter Craig, Concrete Floor Specialist

Rob Hammon, Ph.D., ConSol Energy
Consulting

Jim Holland, CMR, Restcon

Howard Kanare, CTL Inc.

Larry Livermore, American
Architectural Manufacturers
Association

Joe Lstiburek, Ph.D., P.Eng., Building
Science Corporation

Gail McEneany, Sempra Utilities

Don Onysko, Ph.D., DMO Associates

Bill Rose, Ph.D., P.E., University of
Illinois at Urbana-Champaign

Steve Quarles, Ph.D., University of
California Cooperative Extension

Chris Schumacher, Ph.D., University of
Waterloo

Charles Segerstrom, PG&E Stockton
Training Center

John Straube, Ph.D., University of Waterloo

Peter Sierck, CIH, Environmental Testing
and Technology, Inc.

Anton Tenwolde, USDA Forest Products
Laboratory

Elsa Trujillo, Sempra Utilities

Bill Weber, Four-Star Restoration

Scott Wood, Four-Star Restoration

Please cite this report as follows:

Leslie, Neil. 2006. *Final Report for Energy-Efficient, Mold-Resistant Materials and Construction Practices for New California Homes*. Gas Technology Institute for the California Energy Commission, PIER Building End-Use Energy Efficiency Program. CEC-500-2007-036

Preface

The California Energy Commission's Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The PIER Program strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

- PIER funding efforts are focused on the following RD&D program areas:
- Buildings End-Use Energy Efficiency
- Energy Innovations Small Grants
- Energy-Related Environmental Research
- Energy Systems Integration
- Environmentally Preferred Advanced Generation
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy Technologies
- Transportation

Energy-Efficient, Mold-Resistant Materials and Construction Practices for New California Homes is the final report for the Energy-Efficient, Mold-Resistant Materials and Construction Practices for New California Homes Project, (contract number 500-03-013), conducted by Gas Technology Institute. The information from this project contributes to PIER's Building End-Use Energy Efficiency program.

For more information about the PIER Program, please visit the Energy Commission's website at www.energy.ca.gov/pier/ or contact the Energy Commission at 916-654-~~5164~~4878.

Table of Contents

Acknowledgments.....	i
Preface.....	v
Abstract.....	xi
Executive Summary	1
Chapter 1: Introduction.....	5
1.1. Background and Overview	5
1.2. Project Objectives	5
1.3. Team.....	6
1.4. Research Tasks.....	6
1.5. Organization Chart	8
1.6. Report Organization	8
Chapter 2: Situation Analysis.....	11
2.1. Background	11
2.2. Literature Review and Interviews	12
2.3. Integrated Water Damage Claim Database.....	18
2.4. Building Assemblies and Construction Practices for Laboratory Evaluation	24
Chapter 3: Laboratory Evaluation	29
3.1. Background	29
3.2. Objectives	29
3.3. Building Assemblies Laboratory Evaluations.....	29
3.4. Concrete Slab Construction Practices.....	43
3.5. Window Installation Methods.....	48
3.6. Hygrothermal Modeling of Building Wall Assemblies	61
3.7. Recommendations for Demonstration Homes.....	64
Chapter 4: Demonstration Homes	67
4.1. Background	67
4.2. Objectives	67
4.3. John Laing Homes Concrete Slab Demonstration Homes	70
4.4. John Laing Homes Innovative Assemblies Demonstration Homes.....	76
4.5. Clarum Homes Demonstration Home	82
4.6. Demonstration Homes Conclusions and Recommendations	84
Chapter 5: Information Product Dissemination	86
5.1. Background	86
5.2. Objectives	86

5.3.	Builder’s Guide	86
5.4.	Builder’s Training Sessions	89
5.5.	Title 24 Technical Data Dissemination	90
5.6.	Assessment of Project Benefits and Future Initiatives	92
Chapter 6: References		96
Chapter 7: Glossary		97
Chapter 8: List of Attachments		99

List of Figures

Figure 1. Project organization chart.....	8
Figure 2. California climate zones with highest water damage claim rates are located in Southern California.....	21
Figure 3. California counties with highest water damage claim rates	21
Figure 4. Stucco wall construction trends in western states	23
Figure 5. Baseline roof and wall assembly	26
Figure 6. Baseline floor slab.....	26
Figure 7. Wall assembly DAS sensor locations	34
Figure 8. Wall weight load cell apparatus.....	35
Figure 9. Anti-microbial treated gypsum panels vs. conventional gypsum panels	36
Figure 10. Fiberglass gypsum panels vs. conventional gypsum panels.....	36
Figure 11. Wall drying rate profiles normalized to end date.....	38
Figure 12. Drainage profile, 3-coat stucco, housewrap/building paper, OSB	40
Figure 13. Drainage profile, EIFS, 2 layers building paper, OSB	41
Figure 14. Capillary flow at weep screed with water injected at WRB interface	42
Figure 15. Concrete slab layout.....	45
Figure 16. Concrete slabs (looking south)	46
Figure 17. Slab A and B relative humidity profile in 4in slabs at 1-in depth.....	47
Figure 18. Slab A and B relative humidity profile in 12-in grade beam at 1-in depth	47
Figure 19. Capillary-dominated drainage with water poured into sill pan	55
Figure 20. Water from window frame leak collected in sill pan flashing	55
Figure 21. Leakage with sill pan and OSB sheathing.....	56
Figure 22. Leakage with sill pan and open frame construction.....	56
Figure 23. Leak with foam sealant due to misapplication/incompatibility	57
Figure 24. Leak through perforated housewrap during 15-minute blue dye spray test	58
Figure 25. Leaks through perforated housewrap to OSB after stucco application.....	58
Figure 26. Percent moisture content of OSB in wall 1-3A4A5B in all 16 climate zones	63
Figure 27. John Laing Homes Inland Division Secret Garden Development.....	68

Figure 28. Clarum Homes Pajaro Vista Development.....	69
Figure 29. Ten mil vapor retarder installation below sand buffer, slab 39	71
Figure 30. Fifteen mil Stego® wrap installation sequence, slab 25	73
Figure 31. Concrete pour, slab 25.....	74
Figure 32. Slab crack after post tensioning and enclosure, slab 25	75
Figure 33. Wagner Rapid RH TM , in situ relative humidity sensor	75
Figure 34. Housewrap/sill flashing schematic with drainage path	79
Figure 35. Window installation, ASTM E 2112-01R Method A1, Lot No. 76.....	81
Figure 36. Flexible sill flashing with 3/8-in backer rod backdam, Lot No. 78	81
Figure 37. Application of 42-42 in first living area, Lot No. 77.....	82
Figure 38. Continuous duty bath fan/light and timed controller installation, Lot No. 77.....	82
Figure 39. Poor tape adhesion in open frame construction.....	85
Figure 40. Good compatibility between flexible sill flashing backdam and leveling tool.....	85

List of Tables

Table 1. Literature survey categories	13
Table 2. Integrated water claims database documentation.....	19
Table 3. List of building assemblies and practices for laboratory evaluation	27
Table 4. List of building assemblies for laboratory evaluation.....	31
Table 5. Wall assembly drainage rates	39
Table 6. Window installation methods and construction sequences.....	50
Table 7. Window installation method test results summary	54
Table 8. Climate zones used in this analysis.....	62
Table 9. Summary of recommendations for demonstration homes.....	66
Table 10. Concrete Slab Demonstration Homes materials and contacts	70
Table 11. John Laing inland division demonstration homes materials and contacts	76
Table 12. Clarum demonstration home materials and contacts	83

Abstract

The Energy-Efficient, Mold-Resistant Building Assemblies for the New California Homes project was a 30-month project funded by the California Energy Commission, Gas Research Institute, and participating builders, utilities, manufacturers, and consultants. This project investigated residential building construction practices and innovative building assemblies that are resistant to mold formation and growth to identify, evaluate, and recommend cost-effective residential construction practices and building assemblies that resist mold growth in the presence of moisture. The project also published guidelines on building materials and construction practices that prevent or limit moisture migration and provided a relational database linking water damage claims incidences, construction details, and climatic conditions.

Project findings informed California Title 24 building standards revision, and project recommendations were incorporated into seven homes built by Clarum Homes and John Laing Homes Inland Division, with materials provided by 17 participating manufacturers. The demonstration homes provided installed cost and performance information on recommended practices in real-world applications. In addition, several mold risk reduction strategies recommended in this project are being implemented by participating builders. Widespread implementation of this project's recommendation in the new construction market and in future Title 24 revisions could provide significant indoor air quality, cost, and energy efficiency benefits for electricity ratepayers in California.

Keywords: mold risk reduction, builder guidelines, water-resistive barrier, window installation methods, demonstration home, stucco, concrete slab vapor retarder

Executive Summary

Introduction

Modern residential and commercial construction practices in California have increased overall building energy efficiency but have also created conditions that may be conducive to microbial growth. Modern building envelopes do not “breathe” as do their counterparts built in the past. Water that intrudes into envelope cavities in a sustained manner or that does not dry quickly may encourage mold propagation. Further, current construction increasingly involves the use of wood with high moisture content for framing. Once the wall cavity is sealed, the retained moisture contributes to favorable conditions for mold growth. Damp insulation and resulting mold growth compromise building envelope energy efficiency, damage building materials, and affect the health and productivity of occupants.

Purpose

Once mold growth occurs, it is costly to remove and often results in expensive litigation. By understanding the building construction parameters affecting mold growth, it may be possible to reduce or eliminate mold growth, thereby limiting heating and cooling energy losses, reducing building remediation costs, and avoiding human exposures. The Energy-Efficient, Mold-Resistant Materials and Construction Practices for New California Homes project was a 30-month research and demonstration project sponsored by the California Energy Commission, with significant co-funding provided by Gas Research Institute and non-contractual market participants.

Project Objectives

- Identify, evaluate, and recommend cost-effective residential construction practices and building assemblies that resist mold growth in the presence of moisture.
- Publish guidelines on building materials and construction practices that prevent or reduce moisture migration from external or internal sources
- Provide a relational database linking water damage claims incidences, construction details, and climatic conditions
- Provide technical data on mold-resistant building materials and design options for use in revisions to California Title 24 residential building energy standards

Approach

The program included three major technical tasks that supported these goals:

- Situation analysis
- Laboratory evaluation
- Demonstration homes

In addition, the program included an information dissemination task and an administrative task.

Gas Technology Institute led a research team that included two top California builders, authors of California Title 24 provisions and compliance manuals, building scientists with expertise in

mold and moisture control, and market analysts. Gas Technology Institute performed the laboratory investigations and coordinated information dissemination. The Energy Resources Center at University of Illinois at Chicago had primary responsibility for the situation analysis. Architectural Energy Corporation, Douglas Beaman Associates, Indoor Environmental Engineering, Mason-Grant Consulting, and Magus Consulting Services provided expert consulting and training services as appropriate to meet project needs. John Laing Homes Inland Division and Clarum Homes provided builder input throughout the project and performed field demonstrations of innovative building construction on seven new production homes.

A project advisory committee guided the team and provided feedback to the California Energy Commission. Several non-contractual participating manufacturers served as project advisory committee members, provided engineering support to the project team, and supplied materials and training for the laboratory evaluations and demonstration homes. A network of building scientists provided additional engineering support and task report reviews as well as permission to incorporate other guidance and resources into this project. Participating utilities coordinated builder training sessions conducted at their training facilities, provided linkages to participating builders, and offered continued assistance beyond the contract period of performance to ensure continued use of key project results. All products and support by these non-contractual participants were provided at no cost to the project.

Outcomes

The situation analysis generated detailed information on problematic and innovative building assemblies and construction practices for use in the laboratory evaluation and demonstration homes. It also provided a database relating water damage claims to geographic location and weather patterns. This database was useful in understanding the current situation and parameters related to mold formation and growth in California homes.

The laboratory evaluation provided empirical data on the mold resistance of targeted residential building assemblies and constructions. These data were used to identify mold-resistant building materials and systems for use in the demonstration homes. They also formed the technical basis of information products for California Title 24 building standards revisions and for voluntary builder guidelines.

Further, recommendations from the situation analysis and laboratory evaluation were incorporated into seven demonstration homes built by participating builders Clarum Homes and John Laing Homes Inland Division. Materials for these homes were provided by 17 participating manufacturers. The demonstration homes yielded installed cost and performance information on recommended materials and construction practices in real-world applications.

Technical outcomes resulting from this work included:

- Literature review summary.
- Relational database of water damage incidences in California.
- List of baseline and innovative building materials and construction practices.
- Laboratory evaluation of mold and moisture resistance of targeted building assemblies.
- Technical report on relevant Title 24 issues.

- Seven demonstration homes containing innovative assemblies and techniques.
- Demonstration homes summary report.
- Builder training materials and sessions.
- Builder's guide on mold risk reduction strategies for new California homes.
- Recommendations for future initiatives in research and product development.

Anticipated market outcomes resulting from this work include:

- Revisions to residential construction manuals used by building professionals (near term i.e. under two years).
- Improved residential construction practices resulting in higher quality homes (near to medium term i.e. two to five years).
- Future revisions to Title 24 standards, as well as the standards of American Society for Testing and Materials and American Society of Heating, Refrigerating, and Air Conditioning Engineers based on project technical data (long term i.e. five to ten years).
- Enhanced understanding of mold and moisture transport and prevention for future research and applications (near to long term i.e. two to ten years).

Conclusions and Recommendations

Research recommendations based on cumulative project results focus on three major initiatives:

- Expand field demonstration and monitoring of materials and methods with acknowledged energy efficiency, risk reduction, and performance benefits selected for full-scale implementation or further evaluation by builders under this project.
- Develop and evaluate laboratory and field performance test methods for wall penetrations integrated with cladding and wall assemblies.
- Collect and analyze laboratory and field data on root causes and consequences of building envelope failures to identify and evaluate alternative mold risk reduction strategies for window/wall interfaces.

Benefits to California

Benefits to California electricity ratepayers that may accrue as a result of this project include qualitative and quantitative benefits in three different categories:

- Improved indoor environmental conditions
- Cost savings
- Energy efficiency

Participating builders have begun to incorporate into their production homes several strategies to reduce the risk of mold formation and growth based at least in part on recommendations in this project. Specific changes cited in feedback forms include:

- Self-adhering flashing
- Sill pans under windows
- Concrete slab seats under doors

- Class A vapor retarder
- Thicker slab instead of interior grade beams
- Low-noise energy-efficient bath exhaust fan/lights
- Mold-resistant coatings on Oriented strand board and studs in selected areas
- Quality inspection service

Each of these strategies will improve indoor environmental conditions and reduce risk of building failures. A synergistic benefit of this focus on quality will be improved energy efficiency. Envelope details, especially around windows, are critical for as-built construction to perform as designed. While it is difficult to quantify the energy impact of these quality improvements, they are real and may be quite significant.

The research results of the Title 24 investigation in this project have illustrated an opportunity to increase the market impact of energy-efficient air retarding wraps through future revisions to the standard that provide appropriate builder incentives. Builders liked housewraps but consider them too expensive. They prefer the convenience and familiarity of two-ply building paper. Each incremental home constructed with improved air barrier performance would reduce overall home energy consumption by 2 percent or more according to compliance software calculations. Further encouragement to use field verification instead of default credits would also increase market impact of this credit.

1.0 Introduction

1.1. Background and Overview

The Energy-Efficient, Mold-Resistant Materials and Construction Practices for New California Homes project was a 30-month research and demonstration project sponsored by the California Energy Commission, with significant co-funding provided by Gas Research Institute and non-contractual market participants.

1.2. Project Objectives

The goals of the project were to:

- Identify, evaluate, and recommend cost-effective residential construction practices and building assemblies that resist mold growth in the presence of moisture
- Publish guidelines on building materials and construction practices that prevent or mitigate moisture migration from external or internal sources
- Provide a relational database linking water damage claims incidences, construction details, and climatic conditions
- Provide technical data on mold resistant building materials and design options for use in revisions to California Title 24 residential building energy standards.

Technical outcomes resulting from this work included:

- Literature Review Summary
- Relational Database of Water Damage Incidences in California
- List of Baseline and Innovative Building Materials and Construction Practices
- Laboratory Evaluation of Mold and Moisture Resistance of Targeted Building Assemblies
- Technical Report on Relevant Title 24 Issues
- Seven Demonstration Homes Containing Innovative Assemblies and Techniques
- Demonstration Homes Summary Report
- Builder Training Materials and Sessions
- Builder's Guide on Mold Risk Reduction Strategies for New California Homes
- Dedicated Web Site and Associated Content
- Recommendations for Future Initiatives in Research and Product Development

Anticipated market outcomes resulting from this work include:

- Revisions to residential construction manuals used by building professionals (near term)
- Improved residential construction practices resulting in higher quality homes (near to medium term)
- Future revisions to Title 24, American Society of Testing and Materials (ASTM), and American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standards incorporating project technical data as the basis for the revisions (long term)

- Enhanced understanding of mold and moisture transport and prevention for future research and applications (near to long term)

1.3. Team

Gas Technology Institute (GTI) led a research team that included two top California builders, authors of California Title 24 provisions and compliance manuals, building scientists with expertise in mold and moisture control, and market analysts. In addition to leading the project, GTI performed the laboratory investigations and coordinated information dissemination. The Energy Resources Center at University of Illinois at Chicago (UIC-ERC) had primary responsibility for the situation analysis. Architectural Energy Corporation, Douglas Beaman Associates, Indoor Environmental Engineering, Mason-Grant Consulting, and Magus Consulting Services provided expert consulting and training services as appropriate to meet project needs. John Laing Homes Inland Division and Clarum Homes provided builder input throughout the project and performed field demonstrations of innovative building construction on seven new production homes.

A Project Advisory Committee (PAC) guided the team and provided feedback to the Energy Commission. Several non-contractual participating manufacturers served as PAC members, provided engineering support to the project team, and supplied materials and training for the laboratory evaluations and demonstration homes. A network of building scientists provided additional engineering support and task report reviews, as well as permission to incorporate other guidance and resources into this project. Participating utilities coordinated builder training sessions conducted at their training facilities, provided linkages to participating builders, and offered continued assistance beyond the contract period of performance to ensure continued use of key project results. All products and support by these non-contractual participants were provided at no cost to the project.

1.4. Research Tasks

The project included an administrative task and four technical tasks. Project leadership for each of these tasks is shown below:

Task 1 Administration was led by Neil Leslie, GTI.

Task 2 Situation Analysis was led by Douglas Kosar, UIC-ERC.

Task 3 Laboratory Evaluation was led by Neil Leslie, GTI.

Task 4 Demonstration Homes was led by Victor Goochéy, John Laing Homes Inland Division, and John Suppes, Clarum Homes.

Task 5 Information Product Dissemination was led by Neil Leslie, GTI, and Lew Harriman, Mason-Grant Consulting.

The first technical task (Task 2) involved performing a situation analysis of mold problems and state-of-the-art methods to address these problems in California's residential new construction market. The overall goal of Task 2 was to identify the most challenging mold problems facing California builders and recommend potential solutions for detailed laboratory evaluation in

Task 3 and possible use in demonstration homes to be built by the two participating builders in Task 4.

Task 3 laboratory evaluations were designed to provide experimental evidence of moisture loading, propensity for mold formation, and potential performance improvements associated with innovative building assemblies and construction practices. The overall goal of Task 3 was to perform a systematic laboratory evaluation of conventional and innovative residential building materials, assemblies, and construction practices identified in Task 2. These tests generated empirical data (using existing and newly developed test protocols to permit replication by other testing organizations) to provide a technical basis for demonstration home design recommendations, builder guidelines, and future revisions to Title 24 energy efficiency standards. The project team worked closely with the participating builders and manufacturers to identify and recommend mold resistant building systems and construction practices that participating builders used in the Task 4 demonstration homes.

Under Task 4, the two participating builders, John Laing Homes Inland Division and Clarum Homes, incorporated recommended building assemblies and construction practices into six demonstration homes built by John Laing Homes Inland Division in Southern California and one demonstration home built by Clarum Homes in Northern California. The overall goal of Task 4 was to demonstrate mold resistant assemblies and construction practices by building production homes containing building components, assemblies, and construction techniques recommended based on results of Tasks 2 and 3. This task yielded lessons learned based on actual construction practices, guidance on best practices for the Builder's Guide and builder training sessions in Task 5, and construction costs, potential cost savings, and builder benefits from improved construction techniques and materials.

The goal of Task 5 was to disseminate the information products developed during the course of the project to the target customers, including builders, contractors, trade associations, government regulatory agencies, researchers, and consumers.

1.5. Organization Chart

Figure 1 shows the structure of the research project and responsibilities for major tasks and management.

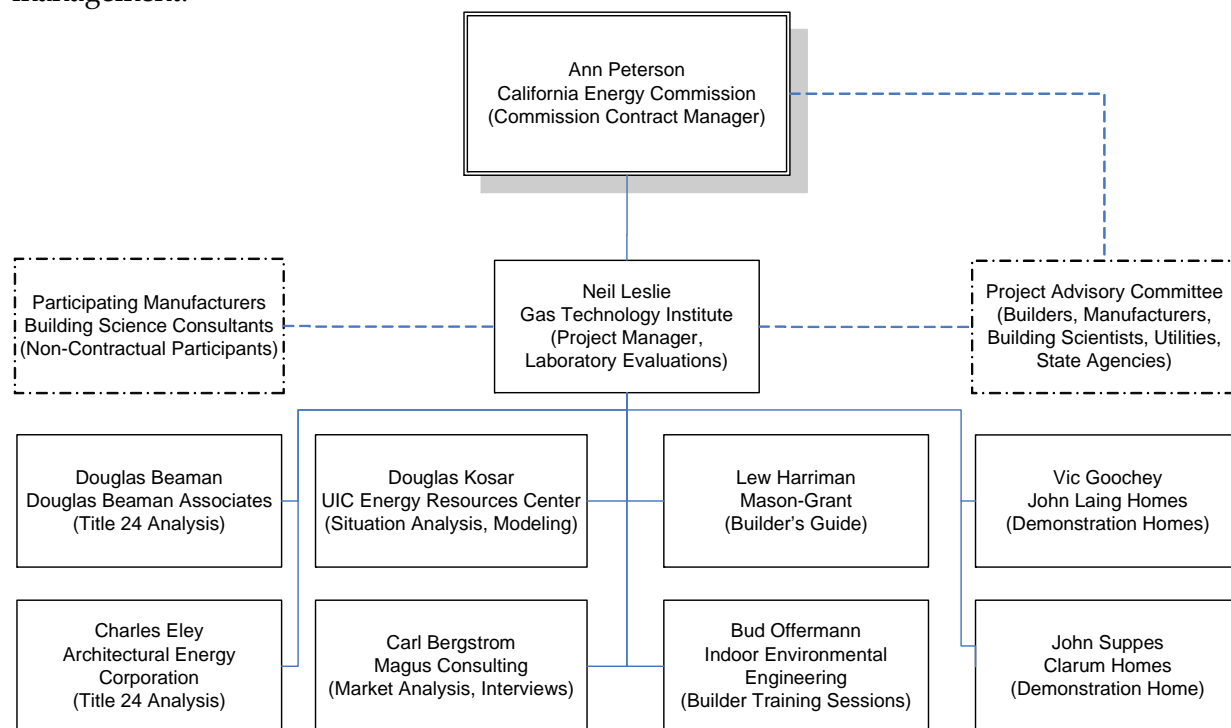


Figure 1. Project organization chart

1.6. Report Organization

Each task in this project addressed independent but linked topics related to energy efficient mold resistant building materials and construction practices for new California homes. This report is organized by the four major research tasks.

Section 2.0 Situation Analysis

Section 3.0 Laboratory Evaluation

Section 4.0 Demonstration Homes

Section 5.0 Information Product Dissemination

Each section contains a summary of the task objectives, followed by the approach, technical outcomes, and conclusions and recommendations. Market connections, future initiatives, and energy impacts are described at the end of Section 5. Key research task reports are separate attachments, including the following:

- Literature Review Summary
- Water Damage Claim Database Manual

- Candidate Building Assemblies and Construction Practices
- Laboratory Evaluation Test Plan
- Building Assemblies Laboratory Evaluation
- Concrete Slab Construction Practices Tests
- Window Installation Methods Tests
- Hygrothermal Modeling of Building Wall Assemblies
- Demonstration Homes Plan
- Demonstration Homes Summary
- California Builder's Guide to Reducing Mold Risk
- Title 24 Air Leakage Reduction Credit
- Builder Training Session Materials
- Benefits Assessment and Future Initiatives

2.0 Situation Analysis

2.1 Background

Modern residential and commercial construction practices in California have increased the overall building energy efficiency, but have also resulted in conditions that may be conducive to rapid microbial growth. Modern building envelopes do not breathe like their counterparts of the past. When water intrudes into envelope cavities in a sustained manner or does not dry quickly, mold may propagate due to “trapped” moisture. In addition, present day construction increasingly involves the use of wood with high moisture content for framing. Once the wall cavity is sealed, the retained moisture contributes to favorable conditions for mold growth. Damp insulation and resulting mold growth compromise building envelope energy efficiency, damage building materials, and affect the health and productivity of occupants. Once mold growth occurs, it is costly to remove and often results in expensive litigation. By understanding the building construction parameters affecting mold growth, it may be possible to mitigate or eliminate mold growth, thereby limiting heating and cooling energy losses, reducing building remediation costs, and avoiding human exposures.

There is a great need to understand the susceptibility of various construction practices and building assemblies to mold growth in the presence of moisture. For instance, a wall assembly consisting of cellulose insulation with high moisture content wood framing and paper-backed drywall with vinyl wallpaper may be highly susceptible to rapid mold growth under high moisture conditions. On the other hand, foamed insulation with proper water drainage channels to outdoors and properly dried wood framing along with fiberglass-backed drywall coated with paint containing mildicide may be less susceptible to mold growth in the presence of moisture. In the mold-susceptible assembly, it will likely be necessary to replace the entire wall assembly, whereas the mold resistant assembly may be salvageable under the same conditions. By improving the understanding of these assemblies and communicating this understanding to builders and energy codes and standards organizations, improved decisions can be made regarding options for retention of envelope energy efficiency and integrity, and avoidance and mitigation of water intrusion, and mold loss prevention.

2.1.1. Objectives

The situation analysis was intended to provide qualitative and quantitative information on the geographic distribution of mold incidences and mold susceptibility of building assemblies currently used in California residential construction. Overall objectives of the situation analysis were to:

- Provide baseline data on problematic and innovative residential building construction practices and assemblies in each California climate zone
- Recommend candidate innovative building assemblies and construction practices for further investigation in Tasks 3 and 4

The objectives were accomplished through a literature review, interviews with stakeholder groups, an integrated water claims database, and risk analysis methods combined with expert engineering judgment.

2.2. Literature Review and Interviews

2.2.1. Objective

The literature review and interviews assembled and evaluated public domain information on problematic and mold resistant residential building materials, assemblies, and construction practices. The ultimate objective of this effort was to provide a preliminary set of recommendations identifying moisture intrusion resistant building assemblies and practices for further investigation and application in the Laboratory Evaluation, Demonstration Homes, and Information Product Dissemination tasks.

Tasks included the following:

- Conduct a literature review of research efforts available in the public domain concerning residential building components and moisture and mold
- As appropriate, interview select building researchers, major homebuilders, and other experts in the field regarding current and future housing subsystems, building material selection, and construction practices
- Prepare a *Literature Review Summary Report* with a bibliography and key findings from the literature reviews and interviews

2.2.2. Approach

To accomplish task objectives, UIC-ERC conducted an interview process and literature review. Table 1 shows the literature survey was organized by categories and the number of reviews. A total of 85 literature reviews were completed based on extensive input from the project team and building science expert interviewees. Targeted and more relevant materials identified by the experts already on the project team and those interviewed in the field reduced the need for a broad based, keyword-driven literature search. The literature survey provided an understanding of the scientific and engineering basis for moisture migration in buildings and ultimately an understanding of current information and guidance on moisture management in homes.

Table 1. Literature survey categories

Major Headings	# Reviews	Shared Subheadings	# Reviews
Building Assemblies	84	Moisture	36
		Mold	2
		Materials	3
		Basement	3
		Crawlspace	2
		Slab	1
		Walls	11
		Vapor Barriers	0
		Windows/Doors	3
Construction Sequencing	1	Roofs	2
		Attics	4
		Plumbing	0
		HVAC	9
		Ventilation	2
		Airtightness	2
		Lighting	1
		Manufactured Housing	4
Totals	85		85

Telephone interviews were conducted with 16 industry experts selected through project team member contacts, as well as during the literature review process. These interviews explored building conditions and construction materials and practices most prone to mold growth, as well as innovative construction materials and envelope designs resistant to moisture and mold growth. Often this was best accomplished by simply asking the industry experts to identify the top three problems related to moisture in homes, and the solutions they have found, or envision, for those problems. Interview results were organized by similar categories as the literature reviews.

2.2.3. Outcomes

Interviews with experts in the field provided an up-to-date sampling of the most relevant issues related to moisture intrusion in building assemblies. The (mostly peer reviewed) literature

created a supporting foundation of information detailing background on the moisture intrusion issues cited by the experts in the field, as well as other issues.

The major water intrusion issues and recommendations cited in the 16 interviews include the following:

- Bulk water

Improper lot grading and settling create slopes toward foundations and allow water to intrude into slabs, crawlspaces or basements; irrigation systems overspray water and repeatedly wet foundations and walls; and roof downspouts are inadequately separated away from homes and deposit water near foundations instead of to a properly sloped grade.

- Roof eaves

Roof eaves lack sufficient extensions outward and permit rain, especially wind-driven rain, to soak exterior porous (brick, stucco, wood, etc.) facades.

- Vapor barriers

Barriers are sometimes incorrectly applied or of the wrong type, depending on climate, and allow moisture to be trapped or build up in walls. Walls need to be able to breathe.

- Window detailing in wall and roof penetrations

- Builders and subcontractors lack sufficient training in proper installation of windows (and flashing).
- Building codes lack standardized window installation practices.
- Standards are non-existent for installation of building membranes and flashings with windows.
- Standards for windows, building membranes, and flashing are outdated (post WW-II ASTM standards) and need to be modernized.
- Trade organizations for fenestration, building membranes, and flashing are needed to foster the needed training, standard, and code activities.

- Plumbing

- Fittings are not always pressure-tested before sealing and can leak undetected for some time behind walls.
- Piping is often punctured by other trades during construction and can leak undetected for some time behind walls.
- Alternative, more robust systems are needed to help remedy these plumbing leaks issues.

- Interior moisture/heating, ventilation, and air conditioning (HVAC)

- Houses are too tight for natural ventilation to be effective. Mechanical outside air (OA) ventilation is needed.
- Architects and engineers need to be educated on ventilation issues and mechanical ventilation options.
- Oriented strand board (OSB) often gets wet during construction and then is not adequately dried before wall and roof construction is completed.
- Some newer paints have much less tolerance to mold growth than paints manufactured 20–25 years ago.
- Domestic hot water heaters, air conditioning coils/drain pans, and ductwork, are placed in attics where leaks can go unnoticed for some time until after substantial damage is done.
- Baths and kitchens exhaust fans are not sized properly and do not operate long enough to reduce moisture to the desired humidity levels. Most of these fans are too noisy, and people are annoyed and limit their operation.
- Wet spray cellulose, if used, is not allowed to dry sufficiently. Moisture content needs to be checked before closing drywall.
- Moisture content in wood framing is often too high before closing in the walls. Moisture content needs to be checked before closing drywall and should not be higher than 19%.
- Miscellaneous
 - A homeowner's manual is needed to address the maintenance issues that could prevent mold incidences over the life of a house.
 - A builder's manual is needed that offers a systems approach to ensuring quality and managing risk during construction. For example, using a series of checkpoints established by extensive litigation and failure analysis, specially trained inspectors can check for specific known anomalies in the building assemblies at greatest risk of water damage and mold formation.
 - Construction sequencing is a clear issue, with poor scheduling leading to unprotected building materials getting soaked with rain/snow on the job site.
 - Elastomeric paints for stucco to limit cracking and water intrusion need to be utilized.

The literature review identified methods by which moisture travels include:

- Pressure differential
- Temperature differential
- Capillary action
- Spills/leaks

- Diffusion

Other literature detailed the points at which traveling moisture intrudes into buildings and their assemblies. The following moisture intrusion problem areas were mentioned frequently in the literature.

Common moisture intrusion points are:

- Penetrations in walls and roofs: windows, doors, skylights, piping through walls, and ductwork through walls and ceilings
- Roofs with improper installation of flashing, or gutters not working properly
- Surface or ground water pooling from improper grading, irrigation system overspray, and improper placement of downspouts
- Interior moisture buildup due to occupant density, improper exhaust venting (bathrooms, kitchen, and laundry), a cooling temperature set point that is too low, and inadequate removal of moisture (insufficient dehumidification)
- Attic/crawlspace moisture from leaky HVAC ducts, condensation on cooler surfaces, and improper ventilation of attic/crawl spaces
- Improperly installed vapor and air barriers; proper placement of air barriers is important to allow building assemblies to dry out
- Infiltration of moist air when leaky HVAC ducts cause pressure differentials, leading to outside air being drawn in to building, and oversized air conditioning equipment, leading to short cycling that reduces the AC equipment ability to dehumidify

Potential solutions that were cited for moisture problems are:

- Use materials that are not prone to moisture build-up and mold formation.
- Provide proper air barrier placement for the building assembly to dry out.
- Provide eaves with at least 18 inches (in) overhang, and do not start siding within 8 in of the ground/soil.
- Increase the cooling set point temperature, and allow the air to flow around the entire space (well mixed conditions). Furniture can block airflow to corners, leading to cold spots and moisture condensation on cooler, dark surfaces. Provide supplemental dehumidification in addition to air conditioning.
- Ensure that flashing is properly installed everywhere, particularly at doors and windows.
- Provide appropriate venting of crawlspaces, as required by the climate. Hot humid climates do not necessarily benefit from natural ventilation of crawlspaces.

2.2.4. Conclusions and Recommendations

On the basis of the interview and literature review, the research team developed the following list of 10 areas for study and evaluation in later laboratory and field activities. These recommendations were used by the project team, participating builders, PAC, and Energy Commission staff to focus laboratory research efforts on high priority areas.

- Upgrading window (and door) installation techniques, standards, and codes to foster proper flashing, etc.
- Improving plumbing systems and installation practices to ensure pressure testing before operation eliminate punctures by other trades, etc.
- Placing HVAC and domestic hot water heater utility closets instead of in attics; where practical, moving ductwork from unconditioned to conditioned spaces.
- Studying role of tight versus loose construction in trapping intruding moisture, providing drying potential, and creating environment for mold growth.
- Finding alternatives to, or enhanced means of, water intrusion protection for hygroscopic building materials such as OSB in wall and roof assemblies (and ensuring that materials such as OSB are sufficiently dry before finishing interior or exterior walls). Likewise, finding alternatives to mold food sources, e.g., substitute fiberglass paper for cellulose on drywall.
- Evaluating proper placement of vapor barriers in wall assemblies, including smart vapor barriers, to inhibit water vapor transport but allow drying under saturated air conditions and new home humidity pulldown.
- Implementing viable drainage plane techniques for porous exterior wall cladding. (Water intrusion needs to be limited. The City of Seattle has been promoting the use of the rain screen wall system since 1999. In the rain screen wall, exterior cladding is set off $\frac{3}{4}$ in from the building wrap and vented top and bottom to provide a drainage plane away from interior wall elements. They also recommend membrane products, such as a “smart” vapor barrier.)
- Extending roof eaves to limit soaking of building exterior wall surfaces and evaluating the role of more complex roof lines on water intrusion.
- Promoting proper grading, along with sufficient roof downspout and irrigation spray separation from foundations and walls
- Producing a homeowners’ manual on methods to maintain a residence to prevent moisture intrusion and mold growth and a builders manual to check during construction for known anomalies leading to water intrusion.

2.3. Integrated Water Damage Claim Database

2.3.1. Objective

The objective of the Integrated Water Damage Claim Database effort conducted by UIC/ERC was to provide a relational database linking mold incidences, climatic conditions, and construction data in California.

The first objective was to establish the quantitative relational database linking concurrent statewide water damage (**not** mold damage) claims, weather conditions, and residential construction statistics. This quantitative database information was to be combined with qualitative insurance, building, and remediation industry survey information (including input on mold damage claim activity) collected during the situation analysis to generate a synthesized database of mold incidences in California.

The PAC and Energy Commission staff determined that a synthesized variant of the water damage claim database based on surveys and interviews would add limited value, since water damage was seen as the precursor to potential mold damage anyways. So in lieu of synthesizing an additional mold damage claim database, additional relational weather and construction databases were developed and evaluated (including detailed precipitation and housing permit, inventory, and age analyses).

Tasks included:

- Obtain water damage claim data from an existing California Department of Insurance (CDI) database for years 2000 through 2002 identifying total number of policies, number of water damage claims, and cost of water damage claims, by county and zip code
- Supplement this insurance industry data set with relevant weather conditions and available building construction statistics for the same time period as the water damage claim data for each of the California counties
- Aggregate these data sets by county, zip code, and California climate zone into an Integrated Water Damage Claims Database and identify preliminary statistical trends in the database

2.3.2. Approach

CDI provided the water damage claim data for years 2000 through 2002 collected under Special Data Call EF-2002 and its Addendum on Earthquake and Fire Experience. No claim data specific to mold damage was collected by CDI.

After a review of the other relational database needs and source options, relevant concurrent weather conditions were obtained from the National Climatic Data Center; and construction statistics were obtained from the U.S. Census Bureau (USCB) and California Department of Finance (CDF). The project team then developed relational databases associating water damage claim activity with key concurrent weather conditions—ambient dew point temperature and precipitation—from a county level basis down to a zip code level basis. The team also created a relational database associating water damage claim activity with key construction statistics—number of single family building permits, number of single family homes, and age of homes—

at a county level. Relational databases were constructed using appropriate statistical software and were ultimately loaded into spreadsheets with accompanying manuals.

Telephone interviews were conducted to gain specific, qualitative information about the incidence and nature of water damage and mold problems in California homes. The goal of these interviews and surveys was to identify problems and potential solutions most relevant to California builders. The purpose was to obtain detailed information on insurance adjustor, builder, and mold remediator experience with mold and home building assemblies, and to provide data to assess California benefits of improved building assemblies. The interviews were a follow-up effort to provide a California focus to the initial, broad-based findings of the literature review and interviews.

2.3.3. Outcomes

A relational database was successfully constructed, including all the supporting manuals and spreadsheets, that provide a detailed discussion of:

- The data collection and reduction process from all data sources
- The aggregation of those individual data sets into three relational versions of the Integrated Water Damage Claims Database
- Statistical trends in the database related to weather and construction data

The supporting manuals are organized as shown in Table 2.

Table 2. Integrated water claims database documentation

Manual	Topic —	Spreadsheet
	Data Sources	
A	Water Damage Claims	NA
B	Weather Conditions	NA
C	Construction Statistics	NA
	Relational Databases	
D	Climate Zone Based	D
E	County Based	E
F	Zip Code Based	F
	Statistical Trends	
G	Water Damage Claims and Weather Data	G
H	Water Damage Claims and Construction Data	H

Analysis of the database identified several trends of interest. On average during the period from 2000 through 2002, 27.2 water damage claims per 1000 policies were experienced annually statewide. Of California's 16 climate zones, zones 10, 7, 15, 14, and 6 (in descending order) experienced above average water damage claim activity. All five are in Southern California (Figure 2). Of California's 58 counties, Riverside, Orange, San Diego, San Bernardino, Contra Costa, Ventura, Solano, and Kern (in descending order) experienced above average water damage claim activity. Of these counties, 5 were in Southern California, and 2 were in the area east of San Francisco Bay (Figure 3).

A Texas Department of Insurance (TDI) mold damage claim database previously demonstrated a statistically significant correlation between ambient dew point temperature and mold damage claim activity. Locations with sustained ambient dew point temperatures at 70°F (21.1°C) or higher along the Texas Gulf Coast showed mold damage claim activity dramatically higher than drier central and western regions of Texas with dew point temperatures below 65°F (18.3°C). Weather data sites throughout California rarely see any sustained dew point temperatures above 60°F (15.5°C). No statistical correlation was found between California water damage claim activity and ambient dew point temperatures. This supports the hypothesis that condensation plane formation in walls is not a likely scenario for water intrusion into building assemblies in California homes.

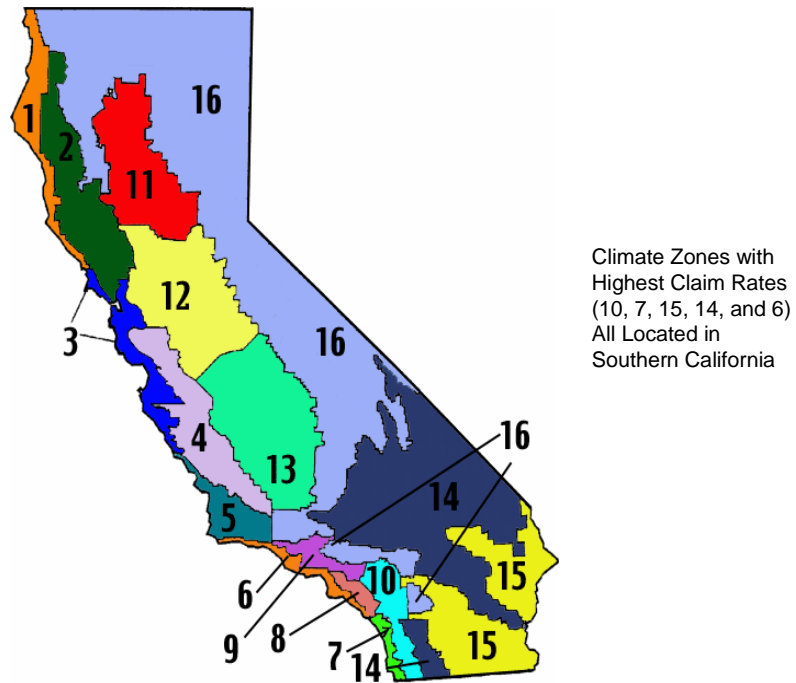


Figure 2. California climate zones with highest water damage claim rates are located in Southern California.

Source: Gas Technology Institute



Figure 3. California counties with highest water damage claim rates

Source: Gas Technology Institute

The other major weather-driven mode for water intrusion is precipitation, especially wind-driven rain. The TDI database did show a correlation, albeit weaker, between increased levels of rainfall and elevated levels of mold damage claims. Some preliminary county level-based correlations in California, using the given county's most populous city as the weather data site, did show trends of increasing water damage claims with increasing rainfall totals. However, a more localized analysis of California weather data on site rainfall and wind-driven rainfall amounts versus water damage claim activity in immediately surrounding zip code areas revealed a scatter plot with no correlation evident. This finding with the California data was not consistent with the correlation between mold damage claim activity and rain data in Texas. However, the lack of any consistent correlation in the California relational databases between rainfall and water damage at a "macro" (county, municipality, or zip code) housing stock level does not preclude rain or wind-driven rain from being a mode for water intrusion and damage at a "micro" (individual or single family) home level.

Construction data did exhibit stronger correlations with water damage claim activity. Counties that issued larger numbers of single-family home permits (higher residential construction activity) generally showed higher levels of water damage claims per 1000 policies. A similar, but weaker, correlation appears in counties with newer single-family home inventories, which generally showed average higher levels of water damage claims per 1000 policies, as well. Finally, counties with larger inventories of single-family homes generally showed higher levels of water damage claims per 1000 policies. Other construction data related to building construction characteristics, such as primary/secondary exterior wall material and foundation type, were not available from the USCB or CDF below the West Census Region level, and hence could not be applied solely to relational databases for California.

Interviews conducted with insurance claims adjusters, mold remediation professionals, air conditioning repair and maintenance contractors, and home builders provided qualitative information on causes and frequency of mold problems. The insurance claims adjusters and remediation experts identified catastrophic problems resulting from equipment, appliance, and fixture failure as the most common source of moisture resulting in mold problems. Further, they estimated about 20–40% of such occurrences also had mold issues. There was no specific type of building assembly identified with a higher propensity for moisture problems.

Air conditioning specialists interviewed were in two groups: those who dealt with day-to-day cleaning and those who specialized in mold. The cleaning firms seemed to lack the knowledge and consistency in approach to accurately assess the extent of moisture and mold problems occurring from air conditioning sources. Mold specialists lacked broad knowledge about the extent of the problem, since they primarily were called after a problem had been identified.

California builders were unanimous in pointing to worker error and quality control as the dominant causative factors for both exterior and interior sources of moisture in new homes. Specific questions about stucco revealed the belief that the current application methods, when followed, would essentially eliminate problems with moisture collection by allowing proper drainage.

Stucco exterior walls dominate new single-family home construction in western states, with 60% market share in 2002 (Figure 4). At the same time, wood siding construction is dramatically declining, with a moderate increase in vinyl siding construction. Brick construction is rare.

2.3.4. Conclusions and recommendations

The integrated water claims database validated the relevance and importance of moisture management and mitigation strategies in the California residential market. This finding holds for both event-related and design-related strategies.

Water damage claims are higher in Southern California than in other regions of the state, even though that area has some of the driest weather in the state. Other correlations were limited, suggesting laboratory research on materials and construction practices should focus on Southern California building practices.

Stucco wall construction presents unique challenges to builders. Since it has such a high market penetration rate, stucco wall assemblies should be a focus of laboratory research efforts on this project.

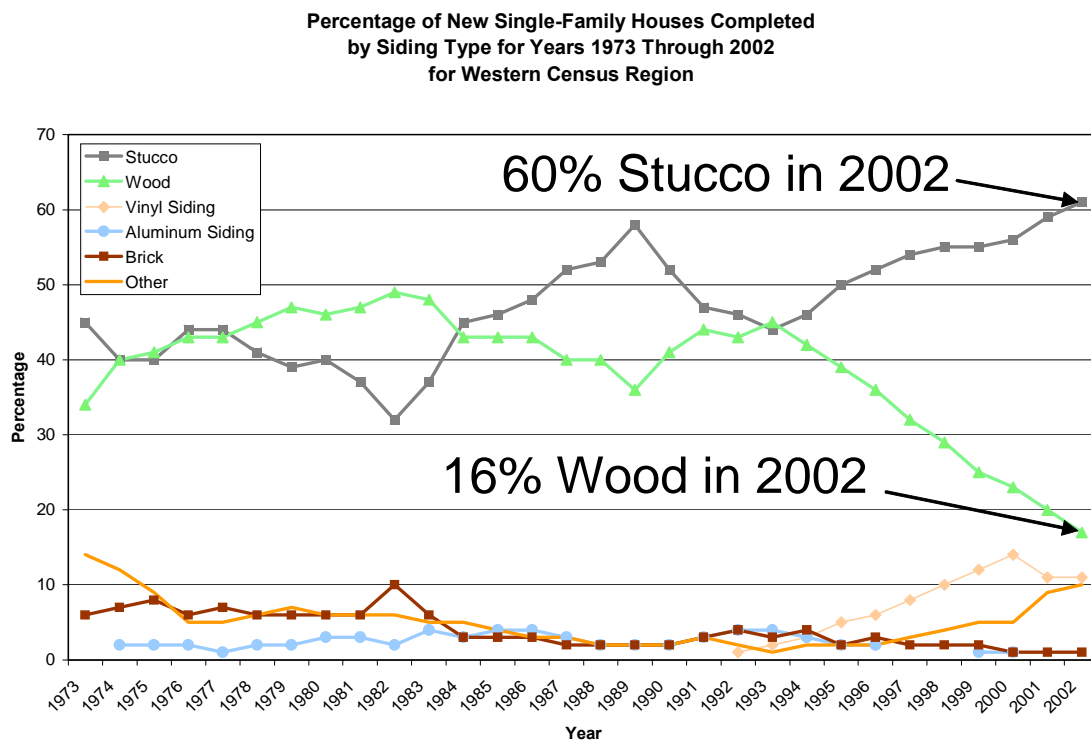


Figure 4. Stucco wall construction trends in western states

Source: Gas Technology Institute

2.4. Building Assemblies and Construction Practices for Laboratory Evaluation

2.4.1. Objective

The objective of this task was to recommend building assemblies and construction practices for detailed laboratory evaluation and possible use in demonstration homes built by the two participating builders.

2.4.2. Approach

Selection of building assemblies and construction practices for laboratory evaluation and demonstration homes was a critical element of the overall project. To achieve the objective, the project team developed and used a selection process that addressed relevant building problems and prioritized potential solutions to those problems. The selection process combined risk analysis methods with expert engineering judgment to develop the recommended list of building assemblies and construction practices. The process used results of information collected in the situation analysis tasks, as well as PAC member input and expertise and project team members' experience, as the basis of final recommendations. Energy Commission staff reviewed and approved the selection process and the recommended list prior to commencing Task 3 laboratory evaluations.

The selection process included the following activities:

- List mold and moisture problems using task 2 information and expert judgment
- Prioritize problems
- Establish baseline building assemblies and practices
- Identify possible improvements to baseline
- Prioritize improvements
- Recommend list of improvements for laboratory evaluation
- Recommend list of improvements for demonstration homes

2.4.3. Outcomes

Baseline building assemblies and construction practices provided the basis of comparison for potential improvements as well as alternatives that may be more susceptible to mold growth in the presence of moisture. The baseline building configuration was based on typical Title 24 stucco construction applicable to most of California's 16 climate zones. Figures 5 and 6 show the baseline configurations for walls, roof, and floors. In climate zones with high heating loads, the only major additional requirement was exterior sheathing insulation.

Selection of innovative assemblies and construction practices focused on items and areas that have not been previously tested in the laboratory. Based on discussions with Energy Commission staff, the project team, PAC members, and building industry experts, the highest value areas to address with laboratory evaluations were water-resistive barrier (WRB) design options (especially around windows), concrete slab installation practices and materials

(especially vapor retarder location and fill materials), and drying times for built up wall assemblies. A preliminary list of recommended improvements for demonstration homes was also developed under Task 2 based on interest expressed by participating builders, and participating manufacturers. The preliminary list included construction site drying, mold resistant coating for sheathing, and mold resistant gypsum panels.

2.4.4. *Conclusions and recommendations*

Table 3 summarizes the list of building assemblies and construction practices recommended for laboratory evaluations conducted under Task 3. The list was reviewed and prioritized by the PAC and by Energy Commission staff at a special PAC conference call and through follow-up discussions with the project team and individual PAC members. This list was updated during Task 3 evaluations based on test requirements and schedule constraints.

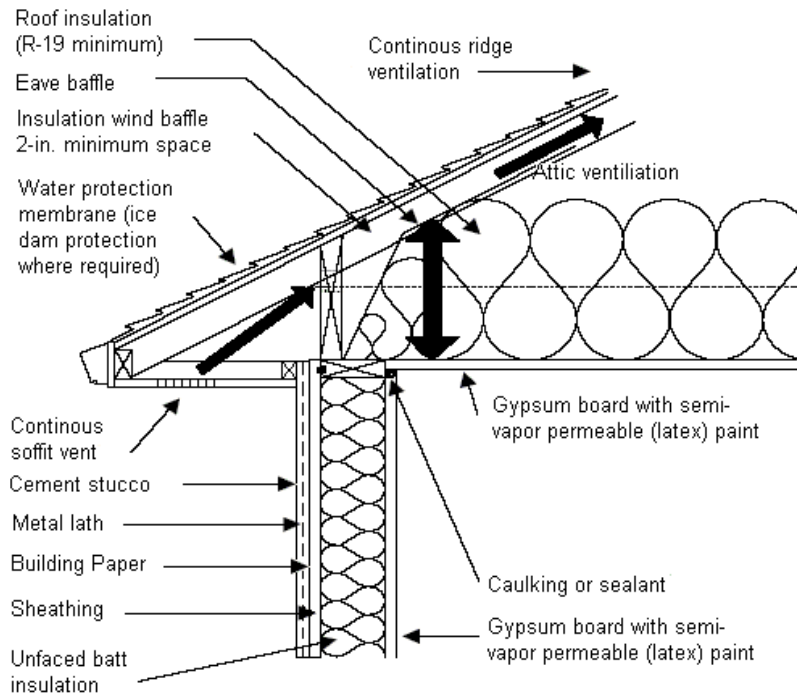


Figure 5. Baseline roof and wall assembly

Source: Gas Technology Institute

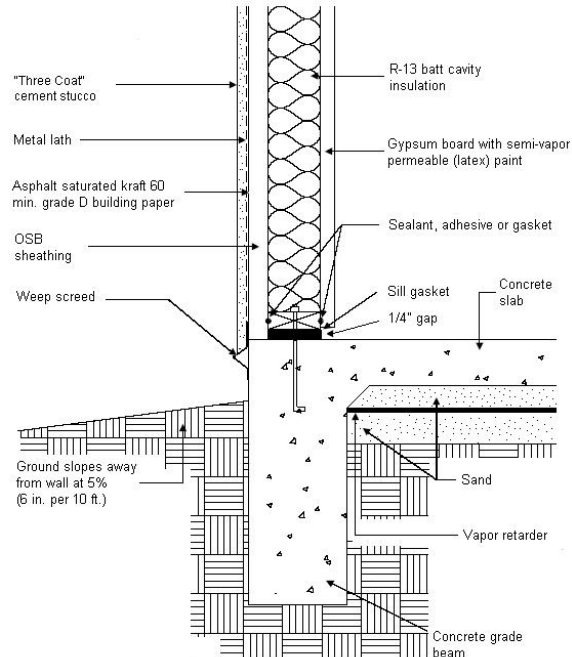


Figure 6. Baseline floor slab

Source: Gas Technology Institute

Table 3. List of building assemblies and practices for laboratory evaluation

Category	Description of Building Assembly
Window Installation Methods (Highest Priority)	This category will examine different window installation methods to evaluate moisture penetration through the drainage plane. Tests will include medium-quality installations to reflect variability in skill levels in the field. Baseline will include vinyl windows, 3-coat stucco.
- ASTM E2112 Method A	Sill flashing; window; jamb flashing; head flashing; weather barrier
- ASTM E2112 Method A1	Weather barrier; sill flashing; window; jamb flashing; head flashing
- ASTM E2112 Method B	Sill flashing; jamb flashing; window; head flashing; weather barrier
- ASTM E2112 Method B1	Weather barrier; sill flashing; jamb flashing; window; head flashing
- CAWM Method A	Similar to ASTM E2112 Method A, different details
- CAWM Method B	Similar to ASTM E2112 Method B, different details
- Silverline	Head flashing over weather barrier
- Marvin	Multiple layers of weather barrier and flashing
- Certainteed	Similar to Method B; extra sill flashing; different sealing details
- Pella	Similar to Method A1; extra sill flashing; different flashing details
- Owens Corning	Felt paper flashing; sealant; no gaps
- One-Coat Stucco	Evaluate joint details at selected windows
Stucco Wall Assemblies (High Priority)	This category will examine different wall assemblies used with stucco to determine the impact of various moisture loading scenarios on stucco drainage planes, wall cavities, and interior finishes. Baseline includes 3-coat stucco, double-wrap grade D building paper over sheer wall, single-wrap grade D building paper, no sheathing away from sheer wall, unfaced batt fiberglass insulation, 5/8-in gypsum board
- High/Low Drainage Openings	Baseline with high/low drainage openings
- No Drainage	Baseline without weep screed
- Stucco Wrap	Baseline with DuPont Tyvek™ Stucco Wrap
- One Coat Insulated Sheathing	Baseline with one coat, insulated sheathing, no drainage channel
- Cellulose Insulation	Baseline with cellulose instead of fiberglass insulation
- Fungicide in Gypsum Board	Baseline with USG Humitek™ anti-microbial treated gypsum panels
- Fiberglass-Faced gyp. Board	Baseline with GP DensArmor™ Plus gypsum panels

- Mold-Resistant Sealer/OSB	Baseline with Foster 42-42 [®] mold resistant sealer
- High Permeance Housewrap	Baseline with Owens Corning Pinkwrap [®] housewrap
- High Permeance Housewrap	Baseline with DuPont Tyvek [™] housewrap
- Low Permeance Housewrap	Baseline with Dow Styrofoam Weathermate [™] housewrap
Concrete Floor Slab (High Priority)	This category will examine the impact of various vapor retarder and fill material locations and options on drying time and pooled water for 4-in concrete floor slabs and grade beams.
- Sand, VR	4-in sand; 10-millimeter (mil) polyethylene sheet; soil
- Sand, VR, Sand	2-in sand; 10-mil polyethylene sheet; 2-in sand; soil
- Sand, VR, CDF	2-in sand; 10-mil polyethylene sheet; 2-in compactable, drainable fill; soil
- CDF, VR, Sand	2-in compactable, drainable fill; 10-mil polyethylene sheet; 2-in sand; soil
- VR, CDF	10-mil polyethylene sheet; 4-in compactable, drainable fill; soil
- VR, Sand	10-mil polyethylene sheet; 4-in sand; soil
- Sand alone	4-in sand; soil
- VR under Grade Beam	10-mil polyethylene sheet also under grade beam; 4-in CDF; soil

Source: Gas Technology Institute

3.0 Laboratory Evaluation

3.1. Background

The first technical task (Task 2) of the Energy Efficient Mold Resistant Building Assemblies and Construction Practices for California Homes project was to perform a situation analysis of mold problems and state-of-the-art methods of addressing these problems in the residential new construction market in California. The overall goal of Task 2 was to identify the most challenging mold problems facing California builders and recommend potential solutions for detailed laboratory evaluation and possible use in demonstration homes to be built by the two participating builders.

The focus on water-resistive barrier design options, concrete slab installation practices and materials, and drying times for built-up wall assemblies was intended to provide defensible, repeatable results that advance the understanding of overall wall system performance. Components and subsystems have been tested for mold growth and impact of moisture by building scientists, universities, and manufacturers. The recommended focus built on that testing to provide a better understanding of the behavior of the entire wall assembly and to collect unique data on the performance of wall cavities and materials as a part of a complete assembly. This approach also allowed testing of flexible and innovative configurations of materials and installation methods using a combination of available test protocols and new test methods developed specifically to meet project goals.

3.2. Objectives

The objective of Task 3 was to perform a systematic laboratory evaluation of conventional and innovative residential building materials, assemblies, and construction practices identified in Task 2. Task 3 laboratory evaluations were designed to provide experimental evidence of moisture loading, propensity for mold formation, and potential performance improvements associated with innovative building assemblies and construction practices.

3.3. Building Assemblies Laboratory Evaluations

3.3.1. Objective

The objective of the building assemblies laboratory evaluations was to test baseline and innovative building assemblies identified in Task 2 in accordance with a Laboratory Test Plan developed in Task 3. To meet this goal, the project team characterized the susceptibility of targeted building components and assemblies to mold growth in the presence of moisture loading conditions (e.g., high humidity, rain, dynamic conditions) in a controlled environmental setting at GTI's laboratory facilities. These evaluations provided experimental data on wall drying rates, propensity for mold growth, and performance improvements associated with innovative wall assemblies, using unique test protocols tailored to meet project goals. Laboratory evaluations were intended to provide a technical basis for demonstration home design recommendations in Tasks 3 and 4 and builder guidelines in Tasks 3 and 5.

3.3.2. Approach

Specific laboratory tests and protocols developed in conjunction with project team members, builders, PAC members, Energy Commission staff, and industry consultants were summarized in the Laboratory Evaluation Test Plan. The test plan provided the initial framework for laboratory evaluations of baseline and innovative wall assemblies. Based on experience gained during the performance of laboratory tests, the project team updated test goals, protocols, facilities, and test matrix to maximize the value of each test. Facilities for the wall moisture loading tests included:

- Two air conditioned bays within the GTI Res/Com laboratory, 8 foot (ft) x 15 ft x 12 ft high each
- Test stands with load cells for two wall assemblies
- Moisture loading ports to inject water into wall assemblies
- Moisture content, relative humidity, and temperature sensors, scale, and load cells
- Infrared camera for surface temperature measurements
- Sensor control and signal conditioning microprocessors for moisture sensors
- Data acquisition system to record and monitor data

Building assemblies laboratory evaluations involved three categories of experiments, each with different protocols to achieve task objectives:

- Susceptibility to mold growth
- Moisture content over time
- WRB drainage capacity

Table 4 lists the building assemblies evaluated in these experiments. Wall assemblies included 3-coat stucco cladding, 1-coat stucco cladding with exterior insulation, and exterior insulation finish system (EIFS) cladding with drainage mat. Structural framing options included open-frame construction and OSB sheathing. WRBs included asphalt saturated building paper and non-perforated higher permeance housewrap.

Table 4. List of building assemblies for laboratory evaluation

Building Assembly	Description
Baseline Stucco Wall	Three-coat stucco, two-ply grade D 60-minute building paper over OSB sheathing, or one-ply grade D 60-minute building paper over open frame, 2x4 wood studs with kraft-faced R-13 fiberglass batt insulation, ½-in gypsum panel, latex primer and finish coat
High/Low Drainage Openings	Baseline with high/low drainage openings
Higher Perm Housewrap	Baseline with DuPont Tyvek® HomeWrap™ for inner layer
High Drainage Housewrap	Baseline with DuPont Tyvek® StuccoWrap™ for inner layer
One-Coat Insulated Sheathing	Baseline with one coat, insulated sheathing, no drainage channel
EIFS	Baseline with EIFS
Cellulose Insulation	Baseline with cellulose instead of fiberglass insulation
Anti-Microbial Gypsum Panel	Baseline with USG Humitek™ gypsum panels
Fiberglass Gypsum Panel	Baseline with GP DensArmor™ gypsum panels
Mold Resistant Sealer	Baseline with Foster® 42-42™ mold resistant sealer

Initial moisture content and mold growth experiments were conducted in accordance with the Laboratory Evaluation Test Plan. The initial moisture content and mold growth protocols failed to differentiate component and wall assembly mold growth performance adequately. Nor did the protocols sufficiently control boundary layers for use with moisture transport models. The protocols were substantially modified based on consultation with PAC members and building scientists with expertise in moisture loading and mold growth experiments.

The revised protocols were designed to provide more suitable conditions for significant mold growth and comparative drying rates for the WRB options evaluated. For mold growth evaluations, the wall assemblies were fully encased in low permeance plastic (shrink wrap) to maintain high moisture content for an extended period. For wall drying experiments, five of the six sides were encased in plastic to bias vapor flow toward the WRB side. The revised protocols were more successful in meeting task goals.

For drainage capacity experiments, water was discharged through a hose nozzle at a controlled and metered flow rate into a 1-in high trough inserted at the top of the wall assembly to measure the equilibrium drainage rate. The trough drained the metered water flow into the wall assembly between the WRB and stucco. Water flow rate for each assembly was adjusted to maintain approximately a ½-in water level in the trough for 30 minutes. Equilibrium drainage

rate and visual evidence of leakage through the WRB toward the interior side of the assembly were noted.

The automated data acquisition system (DAS) for building assembly experiments was a Campbell Scientific CR10X datalogger with two 64-channel multiplexing devices, power supply, battery backup, and Ethernet access. The DAS and related software were designed and installed by Balanced Solutions.

Moisture content sensors included temperature, relative humidity, moisture content, and wood temperature. Temperature and relative humidity sensors were thermistors and thin film capacitance sensors encased in Tyvek® sheathing. Resistance moisture pins and wood temperature thermistors were designed and fabricated for this project by Balanced Solutions, Inc. Figure 7 shows sensor locations for all wall assemblies except the mold-resistant sealer assembly. Moisture pins were located in treated and untreated sections in that assembly.

Two load cell fixtures were designed and constructed at GTI's laboratory facilities to provide precise measurements of wall assembly weight (Figure 8). Each fixture included:

- Wood posts for pivot bearing, embedded in concrete casing
- Pillow block pivot bearing and metal counterweight bar with counterweights
- Compression load cell (0–25 pounds) attached to wood frame
- Adjustable wall hanging clips
- Data acquisition wiring harness and punchdown block

Wall assemblies were hung from each fixture and counterweights added to provide approximately 5 pounds net weight on the compression load cell when dry.

3.3.3. Outcomes

3.3.3.1. Susceptibility to mold growth experiments

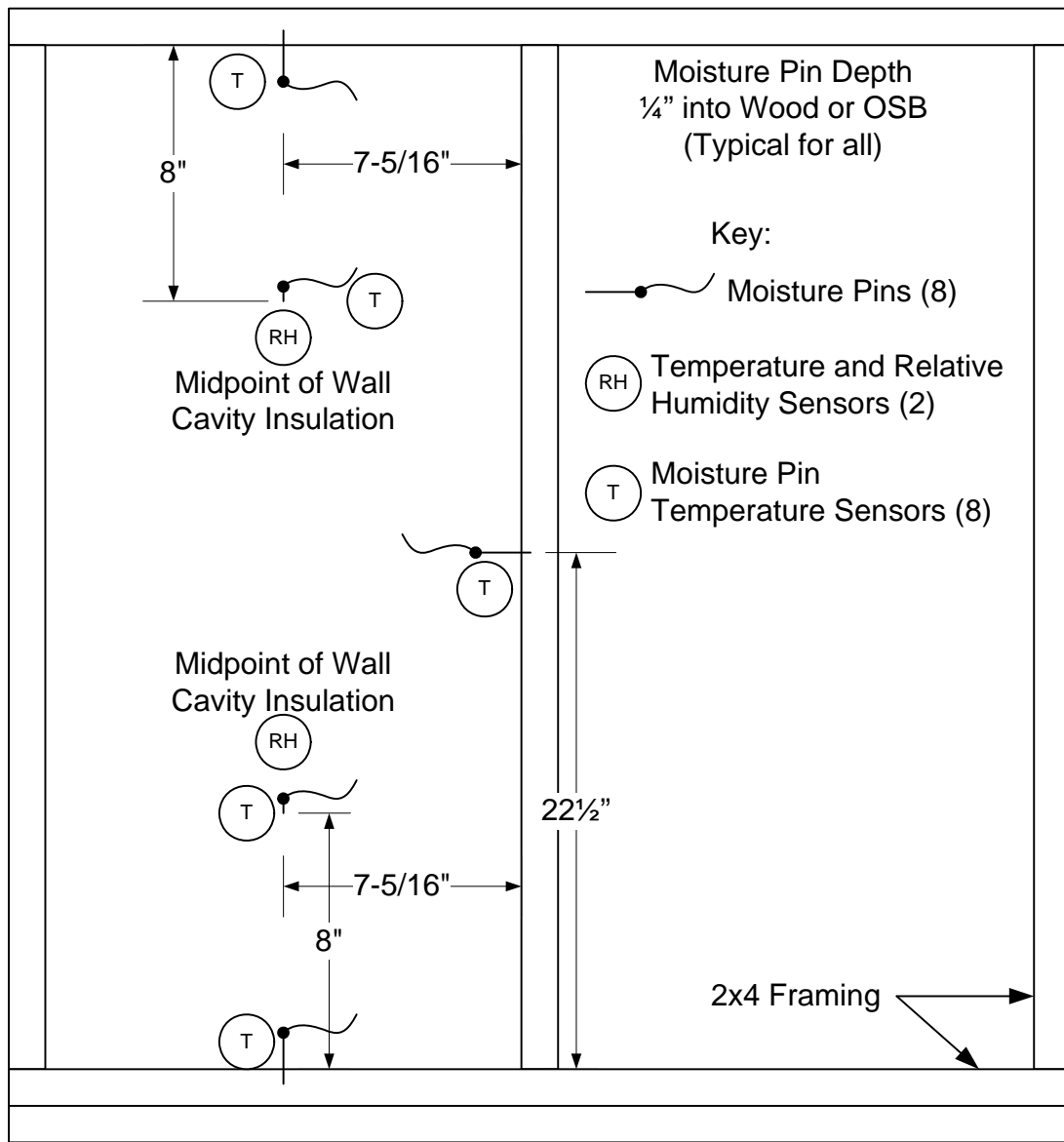
The goal of the susceptibility to mold growth experiments was to compare the susceptibility to mold growth of conventional wall assemblies and mold resistant materials and treatments. The scope of these experiments was to characterize the susceptibility of targeted building components and assemblies to mold growth in the presence of moisture loading conditions (e.g., high humidity, rain, dynamic conditions) in a controlled environmental setting. Targeted building components included:

- Baseline fiberglass insulation
- Mold resistant gypsum panels
- Mold resistant sealer
- Cellulose insulation

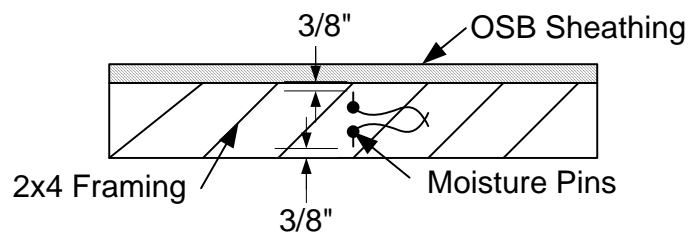
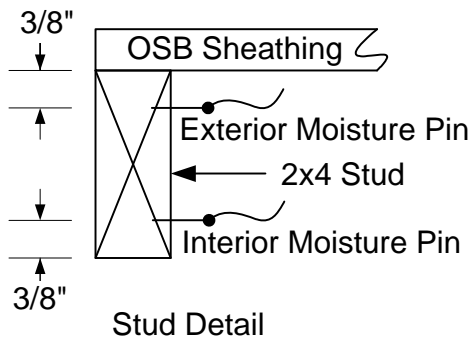
Initial protocols provided some useful information on wall moisture weight, moisture content, and associated mold growth for baseline wall assemblies. However, using these protocols,

relative humidity could not be maintained at levels sufficiently high to promote mold growth, even with periodic water pours.

Revised protocols were more successful in providing suitable conditions for differential mold growth on various surfaces. With the revised protocols, wood and OSB moisture content ranged from 20% to more than 35% (well beyond the upper calibration limit for moisture pins) throughout the experiment period for all experimental wall assemblies. Periodic water pours were successful in maintaining coincident relative humidity at or near saturated conditions.



Wall Section



Base and Top Plate Detail

Figure 7. Wall assembly DAS sensor locations

Source: Gas Technology Institute

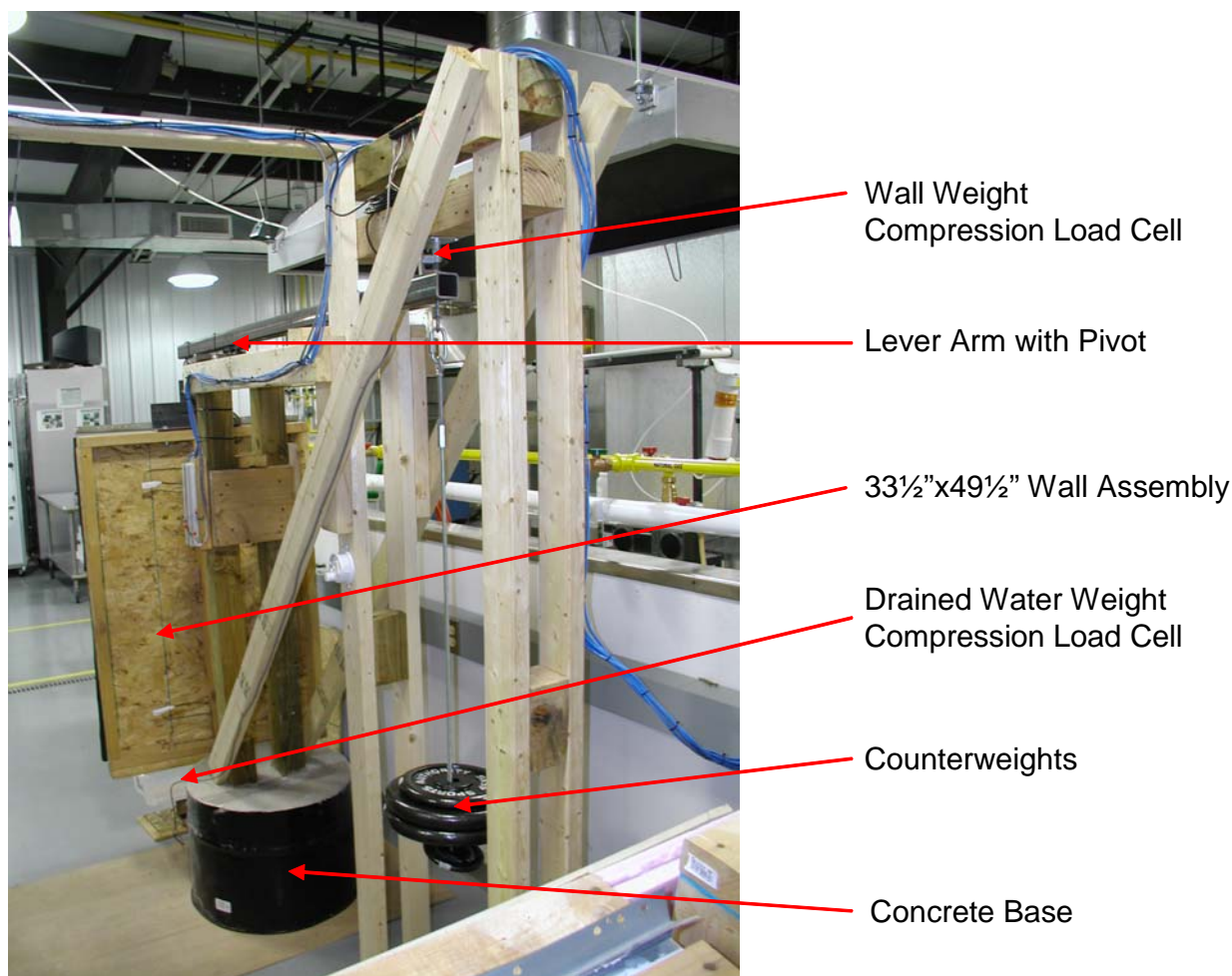


Figure 8. Wall weight load cell apparatus

Source: Gas Technology Institute

All of the wall assemblies in these experiments had kraft-faced fiberglass insulation in at least part of the wall cavity. This enabled an evaluation of several moisture loading parameters and scenarios using both the initial and revised protocols. Using initial protocols, local moisture content and relative humidity in the wall cavity affected mold formation and growth significantly. Moisture content at the bottom of the wall assembly was significantly higher than at all other locations. Relative humidity in the insulation was initially high, but fell after one week, and fell quickly after periodic water pours. Mold growth occurred predominantly at the base plate studs. Little visible mold growth occurred elsewhere, including at the OSB, higher up in the wall, fiberglass insulation, and gypsum panels.

Using the revised protocols, fiberglass insulation experienced visible mold growth on the kraft paper face as well as in the fiberglass adjacent to wood surfaces. More significant mold growth occurred on wood studs and both sides of the gypsum panel. Mold growth on OSB surfaces was visible, but less significant than growth on adjacent wood studs.

Both types of mold resistant gypsum panels exhibited significant resistance to mold growth compared to conventional gypsum panels, but only on the surfaces of the panels themselves (Figures 9 and 10). The remainder of the wall assembly experienced significant mold growth.

The areas treated with the mold resistant sealer, as well as fiberglass adjacent to treated areas, exhibited significant resistance to mold growth compared to untreated portions of the assembly.

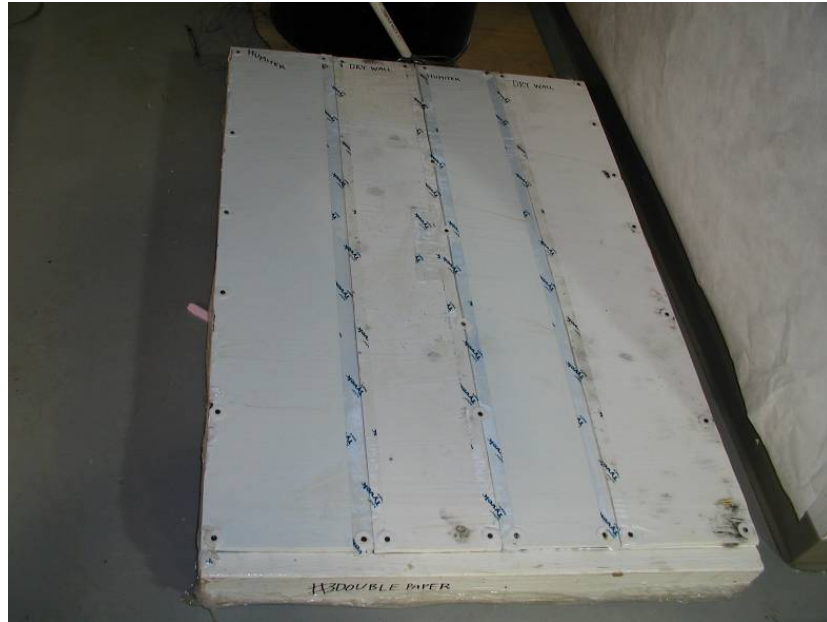


Figure 9. Anti-microbial treated gypsum panels vs. conventional gypsum panels

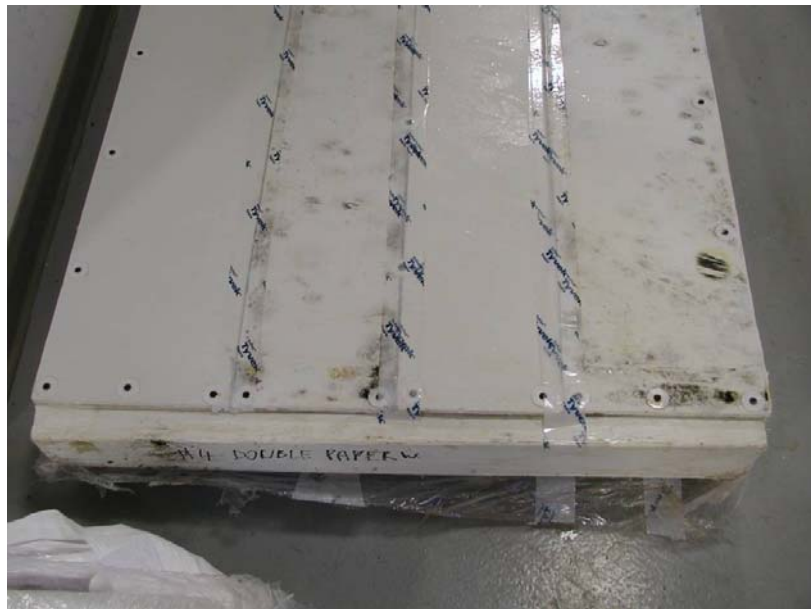


Figure 10. Fiberglass gypsum panels vs. conventional gypsum panels

Cellulose insulation absorbed and retained significantly more water than fiberglass insulation. Moisture content in the OSB and wood studs was at least 10% higher than in other experiments using fiberglass insulation in the cavity. Relative humidity data remained above the calibration range of the sensors for nearly the entire experiment, indicating fully saturated air inside the insulation. Sufficient moisture was present throughout the experiment to be considered conducive to mold formation and growth. In spite of these conditions, the amount of mold growth after the four-week monitoring period was less than initially expected. Both visual inspection and lack of odor indicated little growth inside the cellulose insulation itself, and relatively less mold growth on other surfaces than in other experiments.

3.3.3.2. Moisture content profile experiments

The goal of the moisture content profile experiments was to characterize the moisture content over time of selected wall assemblies, claddings, and WRB options when subjected to water intrusion events. The scope of these experiments was to evaluate the drying rate and moisture content of targeted wall assemblies in the presence of moisture loading conditions in a controlled environmental setting. Selected wall assemblies all had OSB sheathing and included:

- Baseline wall assembly
- Higher perm housewrap
- High drainage higher perm housewrap
- Exterior insulated finish system
- One-coat stucco

The initial approach used for the baseline wall assembly was to pour a specified quantity of water (e.g., 1 pint) into a ½-in diameter hole drilled into the 2x4 wood frame at the top of the wall assembly to simulate a water intrusion event. Caulk was applied to wood seams in an effort to make the wood frame/wall interface water-tight. This procedure did not provide suitable boundary conditions to be of value to either wall drying or as inputs to hygrothermal models. This overall approach was not considered suitable to meet experiment goals. Revised experimental protocols were subsequently applied to the other four wall assemblies to address these issues. The revised procedures were intended to provide more suitable boundary conditions for use in hygrothermal models while focusing on drying rate through the WRB.

Revised protocols designed to focus wall cavity moisture flow toward the WRB and cladding were successful in providing comparative drying rate data on four different wall assemblies. Two walls used three-coat stucco cladding and one layer of higher permeance housewrap coupled with one layer of building paper as the WRB. The two other walls (one-coat stucco and EIFS) used exterior polystyrene insulation combined with two layers of building paper as the WRB. Measurements for the baseline wall assembly (three-coat stucco cladding and two layers of building paper as the WRB) were conducted with the initial flawed protocol, so no comparable data were available for that assembly option.

Wall assembly moisture weight profiles showed differences in evaporative drying rates for different cladding and insulation options. Both walls with exterior insulation were similar to each other and dried more slowly than the two walls with housewrap and no exterior

insulation, which were also similar to each other (Figure 11). Heating the gypsum panel increased the drying rate of each wall slightly.

3.3.3.3. Drainage capacity experiments

The goal of the drainage capacity experiments was to characterize the drainage capacity of selected cladding, WRB, and framing options when subjected to water intrusion between the cladding and WRB. The scope of these experiments was to evaluate the drainage capacities of targeted wall assemblies in the presence of moisture loading conditions in a controlled environmental setting.

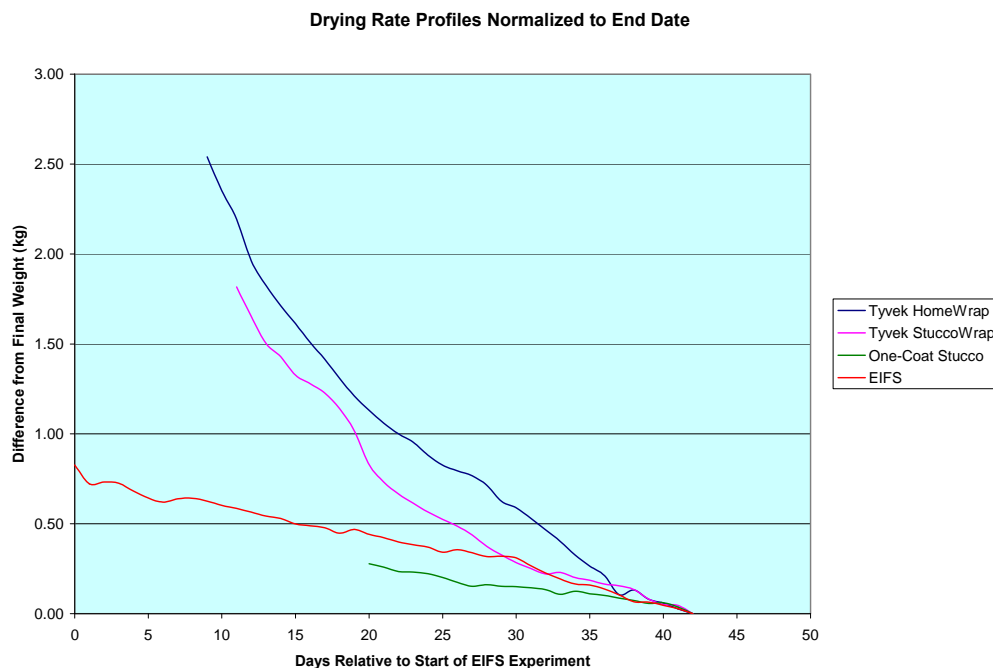


Figure 11. Wall drying rate profiles normalized to end date

Source: Gas Technology Institute

Wall assemblies included:

- Three-coat stucco, two layers building paper, OSB sheathing
- Three-coat stucco with drainage channels, two layers building paper, OSB sheathing
- Three-coat stucco, higher perm housewrap/building paper, OSB sheathing
- Three-coat stucco, high drainage housewrap/building paper, OSB sheathing
- Three-coat stucco, one layer building paper, open frame (no OSB)
- Cracked three-coat stucco, two layers building paper, OSB sheathing
- Exterior insulated finish system, two layers building paper, OSB sheathing
- One-coat stucco (exterior insulation), two layers building paper, OSB sheathing

For these measurements, water was discharged through a hose nozzle at a controlled and metered flow rate into a 1-in high trough inserted at the top of the wall assembly to measure the

equilibrium drainage rate. The trough drained the metered water flow between the WRB and stucco. Water flow rate for each assembly was adjusted to maintain approximately a ½-in water level in the trough for 30 minutes. Equilibrium drainage rate and visual evidence of leakage through the WRB toward the interior side of the assembly were noted.

Table 5 lists equilibrium drainage flow rates for each wall assembly without rain simulation. Rain simulation did not impact drainage capacity for any of the wall assemblies, but did impact leakage through the open frame wall assembly. Drainage capacities of all stucco wall assembly designs with stucco adhered to the weep screed was an order of magnitude lower than for the two walls with full drainage flow channels. Capillary flow through the front of the stucco dominated in these five wall assemblies, and gravity drainage only trickled at the weep screed (Figure 12). The open frame wall assembly behaved differently than the other four stucco walls. The capillary flow through the stucco face was much less than for the other four walls. In this wall, the majority of the water flow actually leaked behind the building paper.

Table 5. Wall assembly drainage rates

Building Assembly	Drainage Flow Rate (gpm)
Three-Coat Stucco, Two Layers Building Paper, OSB Sheathing	0.10
Three-Coat Stucco, Higher Perm Housewrap/Building Paper, OSB Sheathing	0.15
Three-Coat Stucco, High Drainage Housewrap/Building Paper, OSB Sheathing	0.15
Three-Coat Stucco, One Layer Building Paper, Open Frame (no OSB)	0.20
One-Coat Stucco (Exterior Insulation), Two Layers Building Paper, OSB Sheathing	0.20
Three-Coat Stucco, Drainage Channels, Two Layers Building Paper, OSB Sheathing	0.30
Cracked Three-Coat Stucco, Two Layers Building Paper, OSB Sheathing	>1.3
Exterior Insulated Finish System, Two Layers Building Paper, OSB Sheathing	>1.3

Source: Gas Technology Institute



a) Trickle drainage at weep screed



b) Dominant capillary flow through stucco face

Figure 12. Drainage profile, 3-coat stucco, housewrap/building paper, OSB

The wall with two designed vertical drainage channels increased the drainage capacity significantly compared to capillary-dominated drainage. However, since these channels did not provide full face gravity drainage at the weep screed, its total drainage capacity was still much lower than that of the EIFS and cracked stucco wall assemblies, and capillary flow continued to dominate drainage away from the two channels.

Two wall assemblies had significantly higher drainage flow rates, with the maximum measured rate limited not by the WRB capacity, but by the nozzle velocity and the trough slot width. One high drainage capacity assembly was a three-coat stucco wall that had accidentally fallen over onto the stucco face as the finish coat was drying. This cracked the stucco in an unknown way, but provided an opportunity to investigate the impact of stucco cracks on WRB performance. The cracks provided numerous paths for increased gravity drainage, as well as increased capillary flow into the stucco face.

The other high drainage wall assembly was the EIFS with designed drainage mat and weep screed (Figure 13). In this case, the increased gravity drainage capacity was a function of the designed narrow gap between the insulation and the WRB at the drainage mat. Water was able to flow freely to the weep screed whose holes provided designed drainage functionality. This weep screed still provided a screed at the base of the EIFS assembly, but the drainage holes were not plugged by stucco and were able to drain the water very effectively. Holes in weep screeds in the other walls were filled with stucco (as was the entire sloped face of the screed) and provided no gravity drainage capability (Figure 14). Options to address this issue for conventional weep screeds include de-bonding the stucco from the weep screed, and changing the weep screed detail to provide a clear drainage path.



a) Full gravity drainage at weep screed



b) No capillary flow through EIFS face

Figure 13. Drainage profile, EIFS, 2 layers building paper, OSB

Restricted gravity drainage dominated by capillary flow resulted in visible leaks to the interior side of three of the five affected wall assemblies. Leaks occurred through the OSB sheathing itself, and at staple holes through the OSB. The open frame construction with a single layer of building paper exhibited the greatest amount of visible leakage, but it is not known whether there was leakage at the exterior side of OSB sheathing, since that surface was not visible. Neither of the high drainage capacity walls experienced any visible leaks.

3.3.4. Conclusions and recommendations

Data collected under these experiments provided evidence of the beneficial impact of mold resistant materials on mold formation and growth, but only on the materials themselves. The experiments also provided information on drying rates and impact of thermal loading on wall cavity moisture profiles. Finally, drainage capacity experiments demonstrated the importance of providing adequate space for gravity drainage. A capillary break between the stucco cladding and WRB is required for optimal gravity drainage. Additionally, a double layer WRB is essential for stucco walls, with a sacrificial exterior layer for bond break and an interior layer for gravity drainage.

All of the test protocols used in this task were tailored to meet project goals and did not use consensus methods such as ASTM standards. Consequently, all project results are considered informative, but not authoritative. Nonetheless, many of the project results were sufficiently compelling to warrant further research. Research recommendations focus on three major initiatives:

- Collect and analyze laboratory and field data on root causes and consequences of building envelope failures to identify and evaluate alternative mold risk reduction strategies for homes with stucco cladding.
- Develop and evaluate laboratory and field performance test methods for integrated cladding and wall assemblies. The test methods should be realistic and relevant, supported by field data and validated models.

- Perform laboratory and field moisture content and drying rate measurements of new and innovative building assemblies using consensus test methods to provide additional data to validate hygrothermal models.

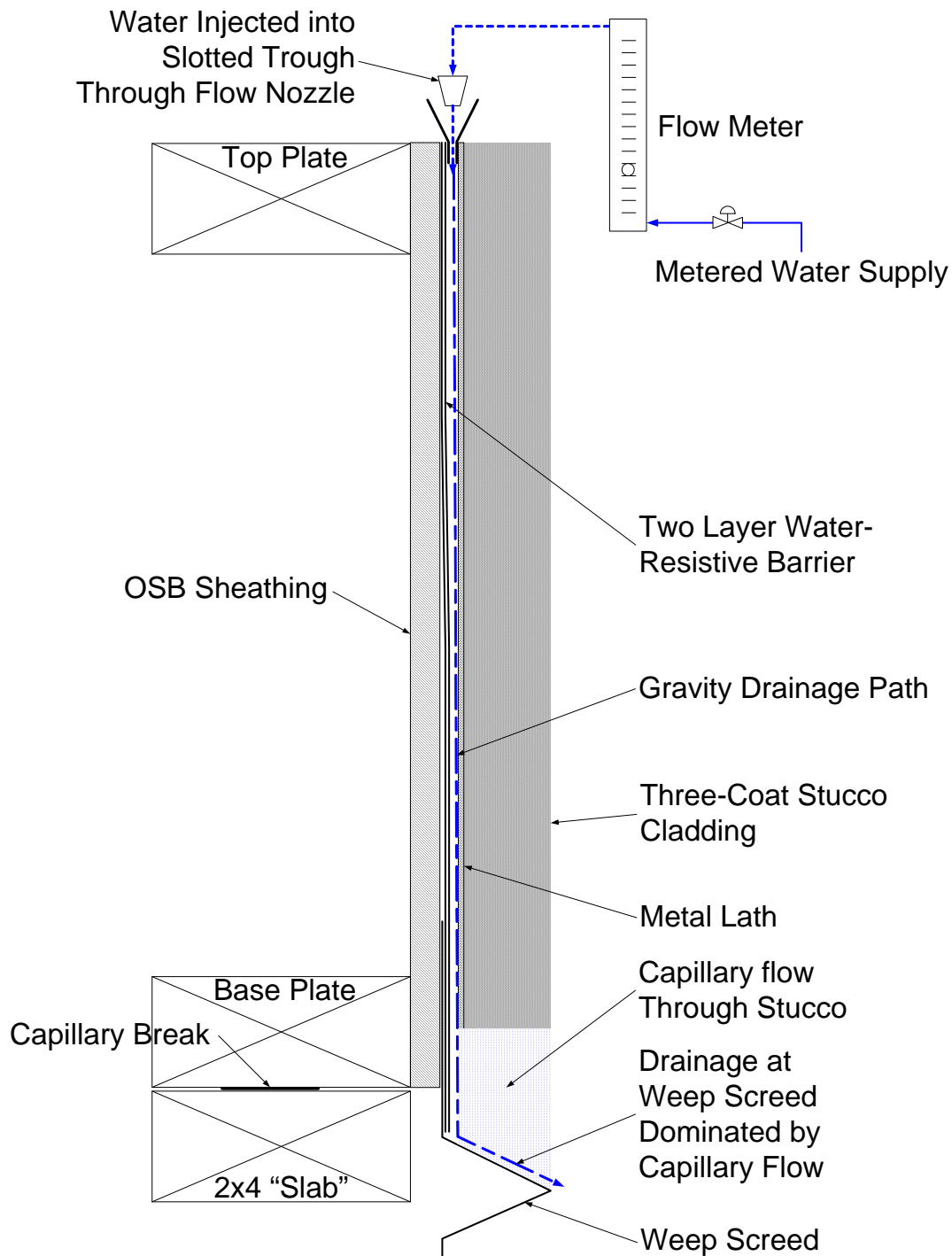


Figure 14. Capillary flow at weep screed with water injected at WRB interface

Source: Gas Technology Institute

3.4. Concrete Slab Construction Practices

3.4.1. Objective

The objective of the concrete floor slab experiments was to measure moisture content over time of concrete floor slabs and footings with targeted vapor retarder locations and fill materials both during the drying period after the slab was poured and when the slab fill materials were subjected to subsequent water intrusion events.

3.4.2. Approach

Concrete slab laboratory experiments focused on vapor retarder installation options described in American Concrete Institute (ACI) 302.1R-04 "Guide for Concrete Floor and Slab Construction". The ACI 302.1 direct contact method was compared to common California contractor practice using slabs constructed and monitored by GTI at its Des Plaines, Illinois, facility. Moisture content experiments on concrete slabs used embedded wood moisture pins and temperature and relative humidity sensors to evaluate slab moisture conditions after the initial pour, after placing glued vinyl tiles on the slabs, and after injecting water into the fill material underneath the slab to simulate changes in water content of the soil. In addition, ambient conditions, soil temperatures, and air temperature above the slab were monitored.

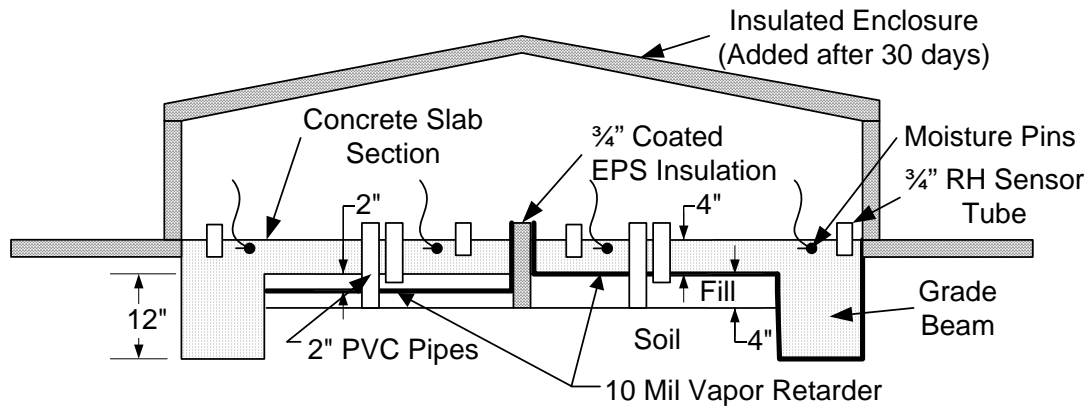
Moisture loading test procedures for concrete slabs evaluated the impact of the vapor retarder location and fill material on curing and drying rates after the pour, and relative humidity and concrete moisture content throughout a heating season, after installing vinyl tiles, and when subjected to water loading from below grade subsequent to the pour. Test parameters included subslab fill material (sand or crushed stone), moisture loading, ambient conditions, and location of vapor retarder relative to the subslab fill material. Measured parameters included temperature and relative humidity of the slab at 1 in below slab surface, moisture content at various depths below slab surface, and temperatures above and below the slab.

Figures 15 and 16 show the eight 4-in thick concrete slab sections and 12-in deep by 12-in wide grade beams, including embedded moisture pins, relative humidity sensors, and water injection tubes. Each slab section was separated from other slab sections using full height ¾-in thick polystyrene insulation boards. To partially decouple the slabs from ground conditions during the Chicago winter, 1.5-in thick by 4 ft-wide polystyrene insulation was placed on the ground adjacent to the slabs.

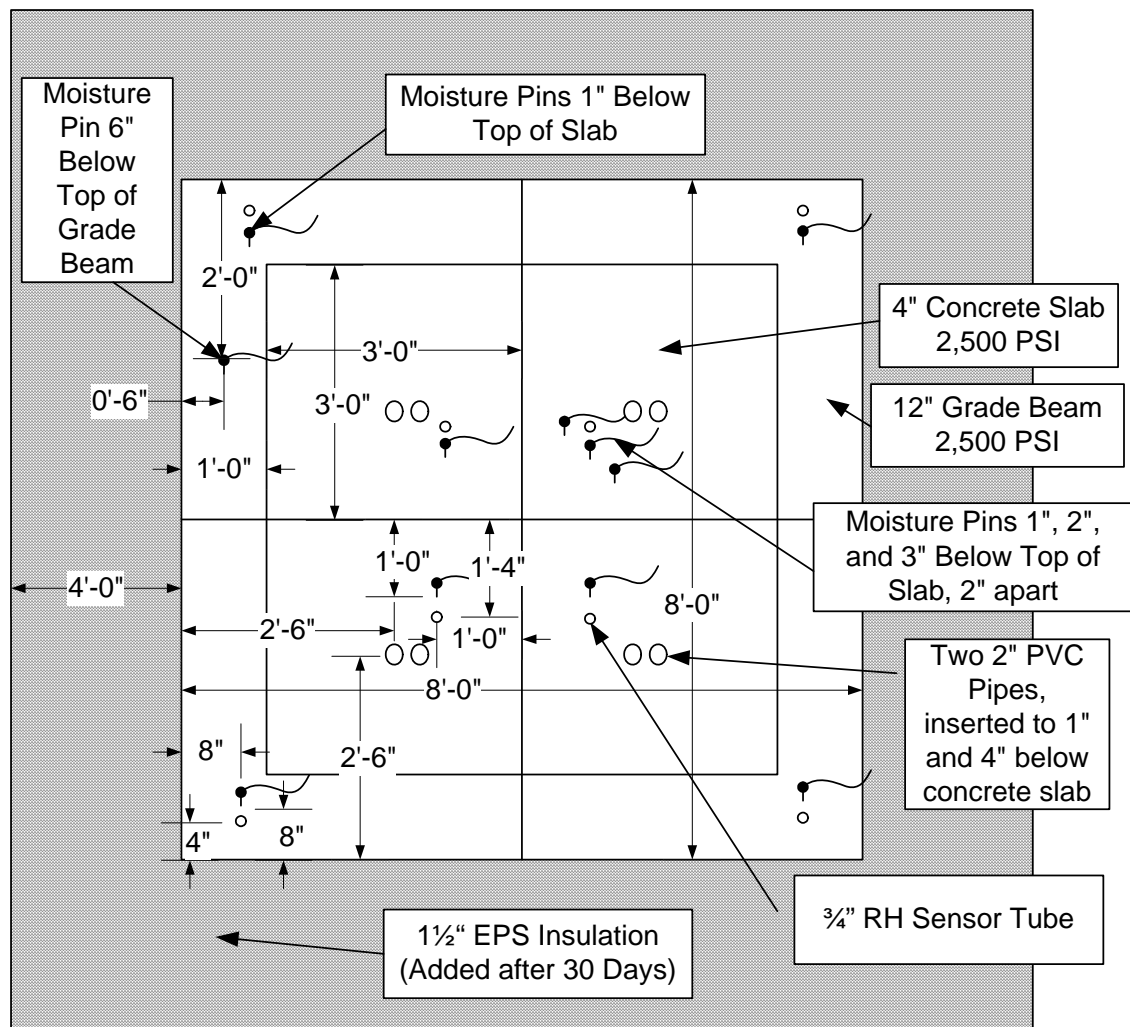
The automated data acquisition system for these tests was a Campbell Scientific CR10X datalogger. Resistance moisture pins inserted into a ¼-in square by 2-in long wood block (designed by Balanced Solutions, Inc., for this project) measured the moisture content of the wood embedded in the concrete. Temperature and relative humidity sensors in the slabs were thermistors and thin film capacitance sensors encased in Tyvek®, inserted into ¾-in ID polyethylene tubes with Tyvek® barrier, and embedded 1 in below the slab surface.

Slabs were poured by hand on October 14, 2004, using nominal 2,500 pounds per square inch (psi) concrete. Initially the concrete slabs were exposed to ambient conditions and not under cover. Slabs were covered with insulated enclosures, and ground insulation was added on November 24, 2004. Slabs remained covered for the remainder of the test period until August

26, 2005. Heating with electric resistance heaters commenced on December 4, 2004, to maintain approximately 20°–22°C (68°–71°F) air temperature above the slabs. Vinyl tiles were glued to slabs on April 5–6, 2005, to determine the impact of sealing the surface on moisture content and relative humidity. The heating setpoint was also lowered to 18°C (64°F) in anticipation of warmer weather. On May 18, 2005, water was poured into the sand or crushed stone under the slabs to simulate groundwater intrusion below the slab. A 2-in PVC pipe inserted at the center of the slab was used to pour water 1 in under the bottom side of the slabs. The amount of water injection was 2 gallons per slab section.



Elevation



Plan

Figure 15. Concrete slab layout

Source: Gas Technology Institute

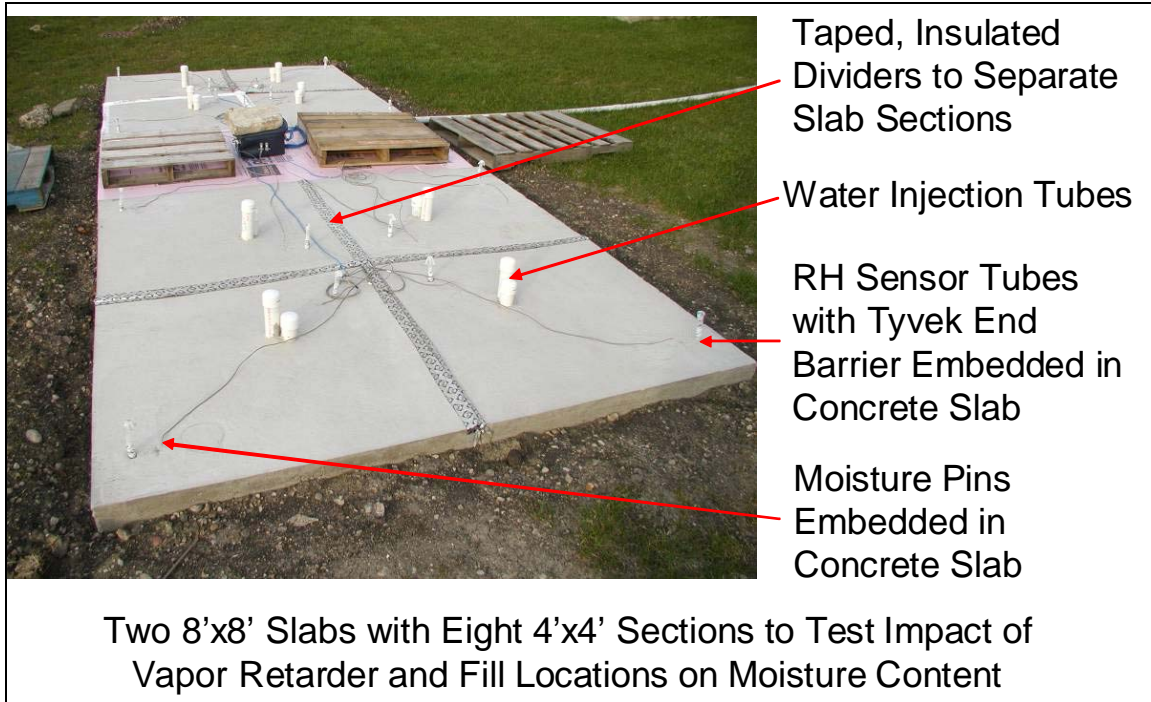


Figure 16. Concrete slabs (looking south)

3.4.3. Outcomes

All eight slab sections had moisture content slopes reasonably consistent with expected drying rates after the slabs were enclosed and heated. Moisture content in all slab sections approached equilibrium 5 months after the pour in March 2005. Vapor retarder location and fill material affected moisture content profiles after slabs were covered, but not always in accordance with expectations. Tile installation did not affect moisture content at 1-in depth in most slab sections, with anomalous changes observed in slabs 2, 3, 4, and 5 immediately after tile installation. The 2 gallon water pour in each slab section resulted in significant changes in moisture content in all five 4-in slabs (1, 2, 3, 4, and 7) not having the vapor retarder directly beneath the slab. Conversely, all three 4-in slabs (5, 6, and 8) with vapor retarder in contact with the slab had much smaller increases, especially in the first month after the water pour. Also, slab 5 moisture content was significantly higher than slab 8 moisture content at 1-in depth in the 4-in slab and at 6-in depth in the grade beam, but not at 1-in depth in the grade beam.

Relative humidity at 1-in depth in all 8 slab sections fell below 80% within 4 months after pour in both the 4-in slab and 12-in grade beam, with significant changes in relative humidity occurring 3 months after the pour, shortly after sensor installation (Figures 17 and 18). Relative humidity variations between the 4-in slab and 12-in grade beam suggest that no entire slab section was ready for floor covering until 4 months after the pour.

The data suggest that moisture content may be a reasonable predictor of changes in relative humidity, but does not appear to be a good predictor of exact relative humidity values in any individual slab section or moisture content level.

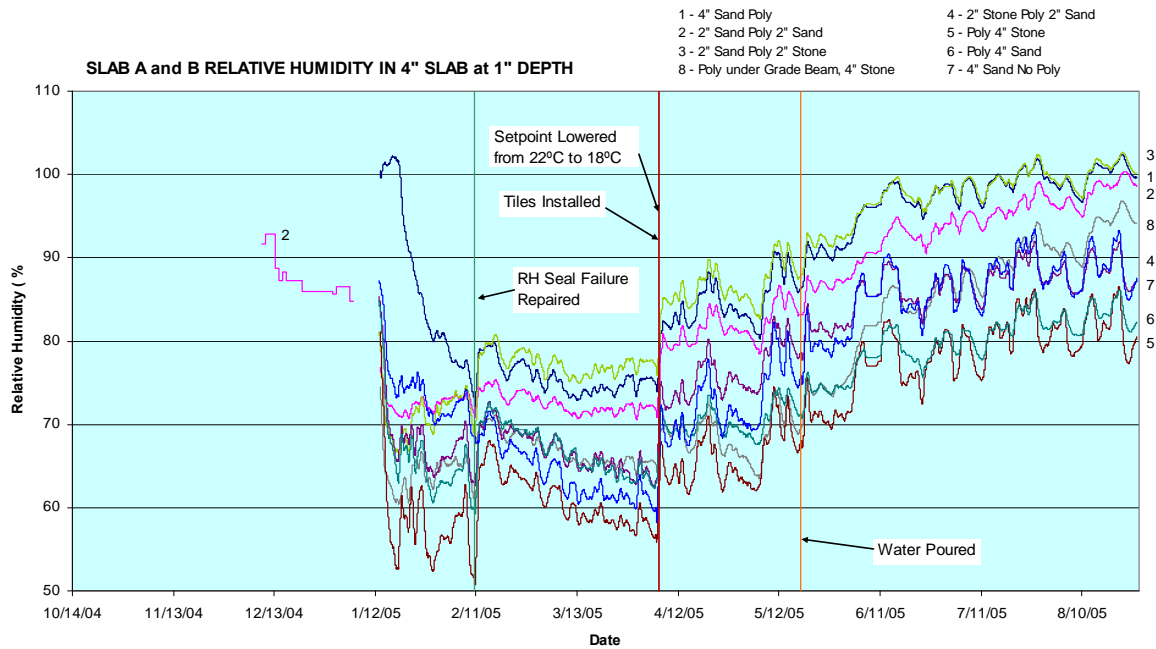


Figure 17. Slab A and B relative humidity profile in 4in slabs at 1-in depth

Source: Gas Technology Institute

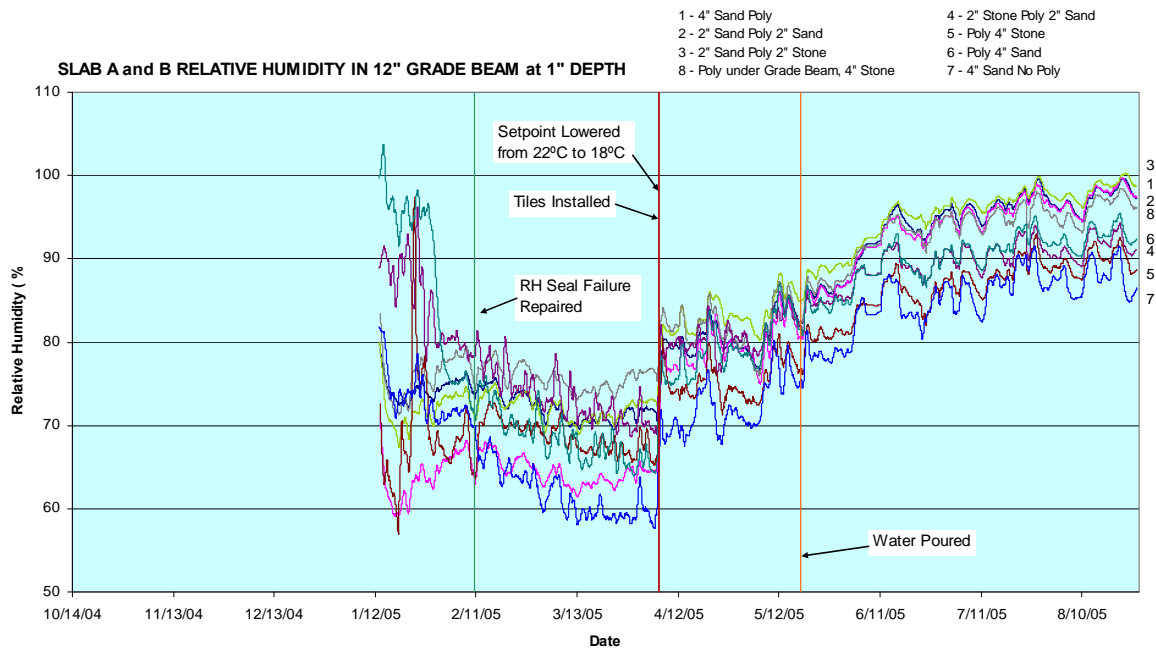


Figure 18. Slab A and B relative humidity profile in 12-in grade beam at 1-in depth

Source: Gas Technology Institute

3.4.4. Conclusions and recommendations

Data collected during these experiments provided evidence of the beneficial long term impact of the direct contact option shown in ACI 302.1R-04 on slab moisture content and relative humidity. The data did not show a noticeable impact of fill material on moisture content or relative humidity. However, the data also yielded some inconsistent and sometimes contradictory results, both for moisture content and relative humidity measurements. Consequently, all project results are considered informative, but not authoritative. Nonetheless, many of the project results were sufficiently compelling to warrant further research.

Additional laboratory and field installations are recommended using collocated moisture pins and temperature and relative humidity sensors to improve the understanding of any correlations among moisture content, relative humidity, and vapor emission rate. An initiative to develop consensus-based test methods and criteria through an organization such as ASTM is recommended to determine and validate the predictive power of various measurement methods.

3.5. Window Installation Methods

3.5.1. Objective

The objective of the window installation methods tests was to evaluate performance of water-resistive barrier design alternatives around conventional vinyl windows in stucco wall construction.

3.5.2. Approach

Water spray test procedures for window installation methods evaluated the ability of the WRBs associated with each installation method to drain all water successfully to the exterior side of the window/wall assembly. The control parameters were window installation methods, cladding, WRB, flashing methods and materials, foam sealant, and window frame leak. The evaluations identified conditions under which observable liquid water leaked into the interior side of the WRB when the window/wall assembly was subjected to simulated rain and leakage events.

Wall assemblies included three-coat stucco cladding, one-coat stucco cladding with exterior insulation, and EIFS cladding with drainage mat. Structural framing options included open-frame construction and OSB sheathing. WRBs included asphalt saturated building paper, perforated housewrap, and non-perforated housewrap. Flashing alternatives included mechanically fastened and self-adhering flashing.

Performance evaluations focused on installation practices and materials recommended in ASTM E2112-01 “Standard Practice for Installation of Exterior Windows, Doors, and Skylights”, as well as draft revisions to the standard recommending sill pan flashing. The evaluation also included selected manufacturer installation methods to compare material, installation, and performance issues with ASTM E2112 guidance. Table 6 lists window installation methods included in the tests.

ASTM E2112 is currently a prescriptive standard. The cognizant committee is exploring appropriate approaches to performance testing methods so materials, practices, and

applications not explicitly covered by the prescriptive practices can be evaluated. The approach and protocols used in this project were intended to assist those efforts by establishing reasonable performance test methods based on current standards for related wall components. Protocols relied on ASTM standards such as ASTM E331 and ASTM E1105 and supplemented those methods with new protocols tailored to meet project goals.

Facilities for the water spray tests included:

- Unconditioned enclosed chamber, 25 ft x 12 ft x 7 ft on asphalt paving
- Test stand for window assemblies
- Pumped, recirculated, dyed water spray rigs with sump below test stands
- Access areas for visual inspection of assemblies during tests

Table 6. Window installation methods and construction sequences

Window Installation Method	Construction Sequence
ASTM E2112-01 Method A (Typically used with building paper)	Install sill flashing; caulk window flanges all 4 sides; install window; caulk exterior side of jamb flanges; install jamb flashing; caulk exterior side of head flange; install head flashing; shiplap WRB (under sill flashing, over jamb and head flashing); apply foam sealant at interior reveals, all 4 sides
ASTM E2112-01 Method B (Typically used with building paper)	Install sill flashing; install jamb flashing; caulk window flanges all 4 sides; install window; caulk exterior side of head flange; install head flashing; shiplap WRB (under sill flashing, over jamb and head flashing); apply foam sealant at interior reveals, all 4 sides
ASTM E2112-01 Method A1 (Typically used with housewrap)	Install WRB with head flashing flap and window opening cuts; install sill flashing; caulk window flanges all 4 sides; install window; caulk exterior side of jamb flanges; install jamb flashing; caulk exterior side of head flange; install head flashing; tape WRB flap shiplapped to head flashing; apply foam sealant at interior reveals, all 4 sides
ASTM E2112-01 Method B1 (Typically used with housewrap)	Install WRB with head flashing flap and window opening cuts; install sill flashing; caulk jamb flanges; install jamb flashing; caulk window flanges all 4 sides; install window; caulk exterior side of head flange; install head flashing; tape WRB flap shiplapped to head flashing; apply foam sealant at interior reveals, all 4 sides
ASTM E2121-01R Draft Method A (Typically used with building paper)	Install sill flashing; install pan flashing (Note: access to adjust shims impeded by back dam with this method); caulk window flanges except sill; install window; caulk exterior side of jamb flanges; install jamb flashing; caulk exterior side of head flange; install head flashing; shiplap WRB (under sill flashing, over jamb and head flashing); apply foam sealant at interior reveals, all 4 sides (Note: no sealant applied at pan flashing for experiments)
ASTM E2112-01R Draft Method B (Typically used with building paper)	Install sill flashing; install pan flashing (Note: access to adjust shims impeded by back dam with this method); install jamb flashing; caulk window flanges all 4 sides; install window; caulk exterior side of head flange; install head flashing; shiplap WRB (under sill flashing, over jamb and head flashing); apply foam sealant at interior reveals, all 4 sides (Note: no sealant applied at pan flashing for experiments)
ASTM E2112-01R Draft Method A1 (Typically used with housewrap)	Install WRB with head flashing flap and window opening cuts; install sill flashing; install pan flashing (Note: access to adjust shims impeded by back dam with this method); caulk window flanges except sill; install window; caulk exterior side of jamb flanges; install jamb flashing; caulk exterior side of head flange; install head flashing; tape WRB flap shiplapped to head flashing; apply foam sealant at interior reveals, all 4 sides (Note: no sealant applied at

	pan flashing for experiments)
ASTM E2112-01R Draft Method B1 (Typically used with housewrap)	Install WRP with head flashing flap and window opening cuts; install sill flashing; install pan flashing (Note: access to adjust shims impeded by back dam with this method); install jamb flashing; caulk window flanges except sill; install window; caulk exterior side of head flange; install head flashing; tape WRB flap shiplapped to head flashing; apply foam sealant at interior reveals, all 4 sides (Note: no sealant applied at pan flashing for experiments)
Marvin Instructions (Building paper used in experiments)	Install 9-in building paper at sill; install self-adhering flexible sill flashing (no back dam approach specified) to cover sill entirely (Note: access to adjust shims impeded by back dam if pan flashing chosen for this method); install 13-in wide building paper at jambs, overlapped and cut to cover rough opening; caulk window flanges except sill; install window; apply loose insulation or foam sealant at interior reveals; install drip cap caulked on back sides; for housewrap, install WRB with head flashing flap and window opening cuts; install self-adhering jamb flashing; install self-adhering head flashing; for building paper, shiplap double layer building paper (under sill and jamb flashing, over head flashing); for housewrap, tape WRB flap shiplapped to head flashing
Pella Southwestern Stucco Instructions (Building paper used in experiments)	Install mechanically fastened sill flashing; install mechanically fastened jamb flashing; install self-adhering flashing tape (no back dam approach specified) to cover sill entirely; install window (no caulk); install self-adhering jamb flashing tape; install self-adhering head flashing tape; install mechanically fastened head flashing; shiplap WRB (under sill flashing, over jamb and head flashing); apply foam sealant at interior reveals, all 4 sides
Owens Corning Instructions (Building paper used in experiments)	Install 8-in to 12-in felt paper at sill with 1-in fold on sill; caulk window flanges all 4 sides; install window; pack insulation at interior reveals, all 4 sides; install felt paper at jambs; install felt paper at head; use common sense to complete exterior
CertainTeed Instructions (Building paper used in experiments)	Install mechanically fastened sill flashing (8-in plus sill width), folded and cut to cover entire sill plus 9-in up jamb; caulk perimeter of rough opening except sill; install window; install jamb flashing; install head flashing; shiplap WRB (under sill flashing, over jamb and head flashing); pack insulation at interior reveals, all 4 sides, do not use foam sealant at interior reveals (Note: foam sealant used in experiments)

Each window was installed according to construction details described in the method under test (e.g., ASTM E2112-01, Method A). Clear and dyed water spray simulated wind-driven rain on the vertical surface of the 24-in x 36-in vinyl sliding windows installed in wood frame wall assemblies with three-coat stucco, one-coat stucco, or EIFS cladding. Each window assembly was sprayed before and after stucco application for a specified period of time to simulate desired rainfall patterns and to explore the ability of the WRB options to shed bulk water intrusions as well as incidental water.

Fourteen of the 15 window/wall assemblies used a single layer WRB. The 15th assembly used double layer construction specified in the installation instructions. California code requires a second layer of building paper over wood sheathing. However, to meet project objectives and allow reasonably equivalent comparisons, a single layer was used for both open frame and OSB sheathing assemblies.

To simulate a minor leak due to a cracked window flange, 1/8-in holes were drilled at the welded seams in the lower two corners of each window after initial tests of the finished stucco walls. To simulate a more significant leak and provide head pressure through the holes, drainage weep holes in the window frames were then plugged.

To examine the impact of sealant on leaks with head pressure, foam sealant was then applied to all reveals, except at plastic sill pans. To avoid any issues with inadvertent cuts when trimming, the foam sealant was not trimmed for any tests.

The measurement parameter for these tests was visual evidence of water penetration behind the WRB. For open frame construction, visual observation did not require dyed water. For walls with OSB sheathing, all experiments were conducted with clear water to examine leaks on the interior side of the sheathing. The final experiment was repeated with dyed water, followed by destructive evaluation of the exterior side of the sheathing. Any water stains were noted and photographed.

3.5.3. Outcomes

Table 7 summarizes test results for each installation method/stucco wall assembly tested. Only 1 of 15 assemblies (a sill pan flashing method) had no observable leaks under all test conditions. Leaks occurred in 14 of 15 assemblies during the most challenging experiment (drilled 1/8-in holes and plugged weep holes in window frames, no interior sealant). Stucco cladding with caulked windows deflected bulk water effectively. Remaining “incidental” water from capillary suction did not leak through the WRBs with any window installation method, with the possible exception of perforated housewrap.

Observations from these tests include the following:

- Stucco moisture transport mechanisms are complex.
- Mechanisms include barrier, capillary suction, gravity drainage, vapor diffusion.
- Different mechanisms dominate depending on design, installation, and maintenance.
- Porous material complicates drainage flows.
- Stucco drainage mechanisms impacted WRB drainage capacity and leak risk.

- Capillary moisture transport (liquid wicking/soaking) provided relatively slow drainage at the interface between stucco and the WRB, and transported liquid water to both sides of the stucco cladding as well (Figure 19).
- Reduced gravity drainage capacity from capillary-dominated moisture transport caused leaks from bulk water collected by sill pan flashing.
- Sill pans effectively collected water leaking through window frame (Figure 20).
- Bulk water under head pressure (due to height between the sill pan and leak site with restricted drainage) leaked through small holes in the WRB at sill pan/WRB joint or through staple holes (Figures 21 and 22).
- Bulk water collected by the sill pan did not leak under head pressure when there were no holes in the restricted drainage path.

Table 7. Window installation method test results summary

Assembly	Wood Sill Covered	Observed Leakage				
		No Stucco	With Stucco, Caulked Except as Noted	Caulked, With Drilled 1/8" Holes	Drilled Holes, Plugged Weep Holes	Plugged Weep Holes, Foam Sealant
1	No	No	No	No	Yes	No
2	No	No	No	No	Yes	No
3	Yes	Yes*	No	No	Yes	Yes
4	Yes	No	No; Not Caulked	No	No	No
5	Yes	No	No	Yes	Yes	Yes
6	Yes	No	No	Yes	Yes	Yes
7	Yes	No	No	No	Yes	Yes
8	Yes	Yes*	No	No	Yes	Yes*
9	No	No	No	Yes	Yes	Yes
10	Yes	No	No	No	Yes	No
11	Yes	No	Yes; Not Caulked	Yes	Yes	No
12	No	Yes	No	Yes	Yes	Yes
13	No	Yes	Yes; Not Caulked	No	Not Tested	Yes
14	Yes	No	No	No	Yes	No
15	Yes	Yes	No	No	Yes	No

* Leakage Occurred in Wall Assembly Away from Window/Wall Interface

No Leaks with Full Stucco/Caulk Seal

No Leaks Under All Tests In Only One Case

No Leaks with Most WRB's Without Stucco

Perforated WRB Leaks With/Without Stucco

Leaks Most Often with Most Severe Test

Foam Sealant Contained Leak in Some Cases

	No Leak, Sill Protected
	No Observed Leak, Sill not Protected
	Observed Leak

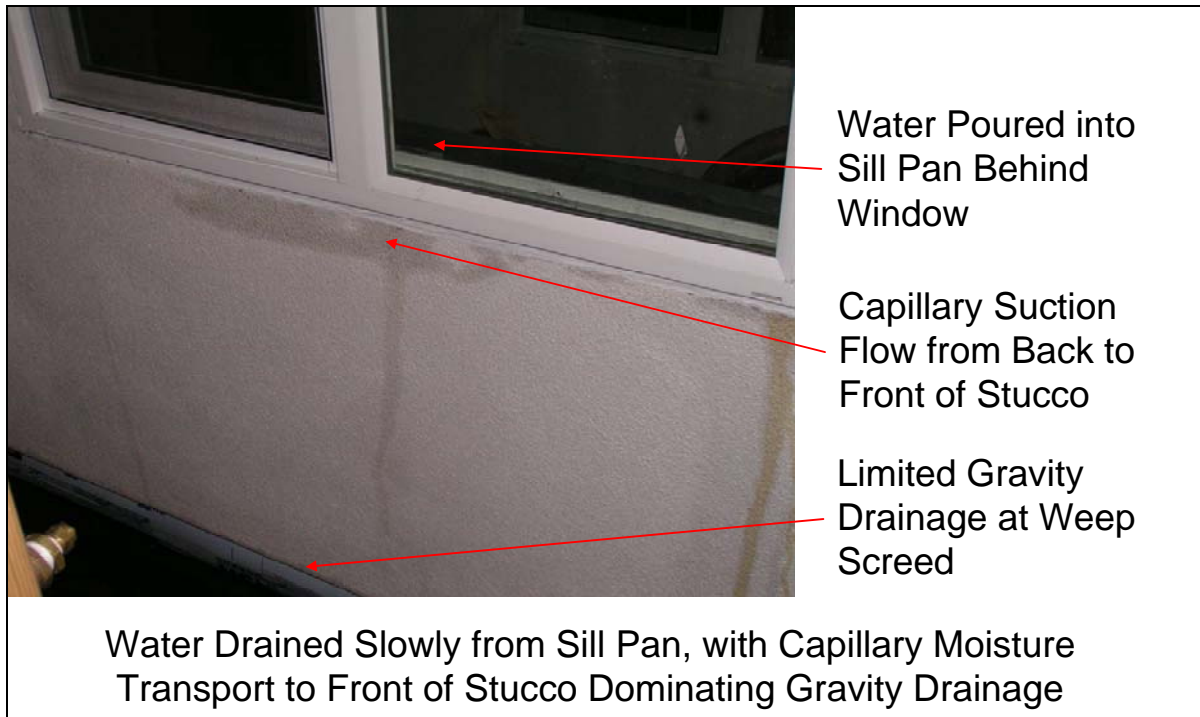


Figure 19. Capillary-dominated drainage with water poured into sill pan



Figure 20. Water from window frame leak collected in sill pan flashing

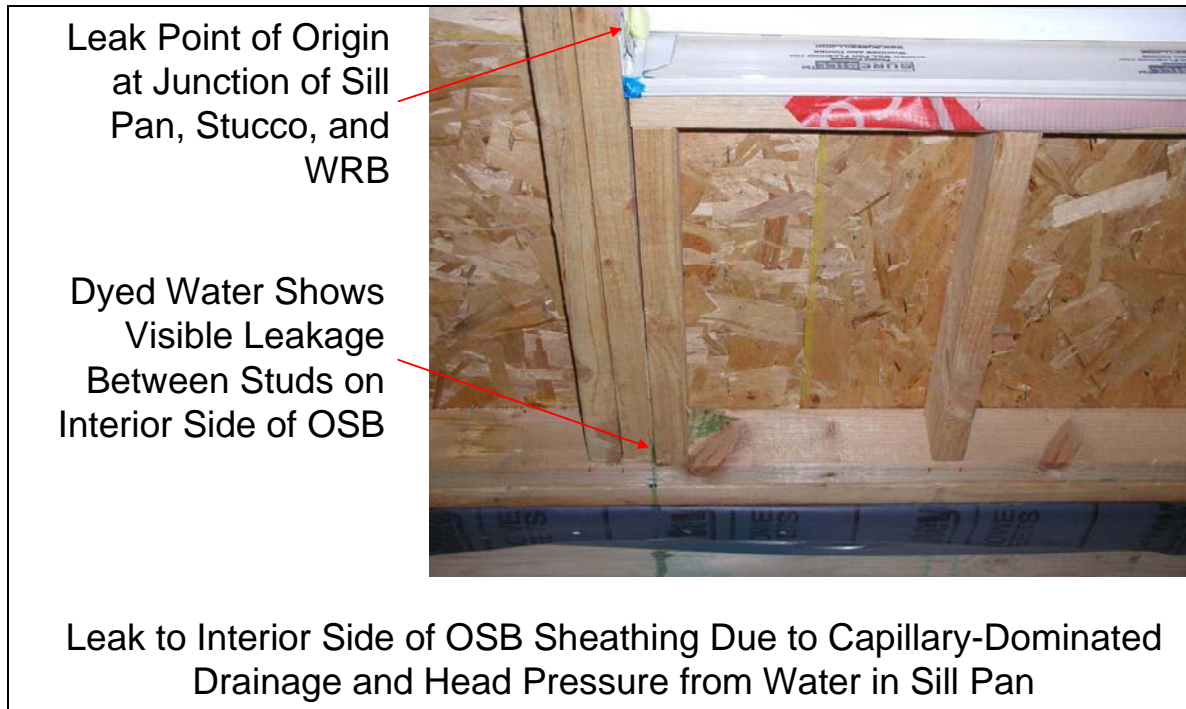


Figure 21. Leakage with sill pan and OSB sheathing

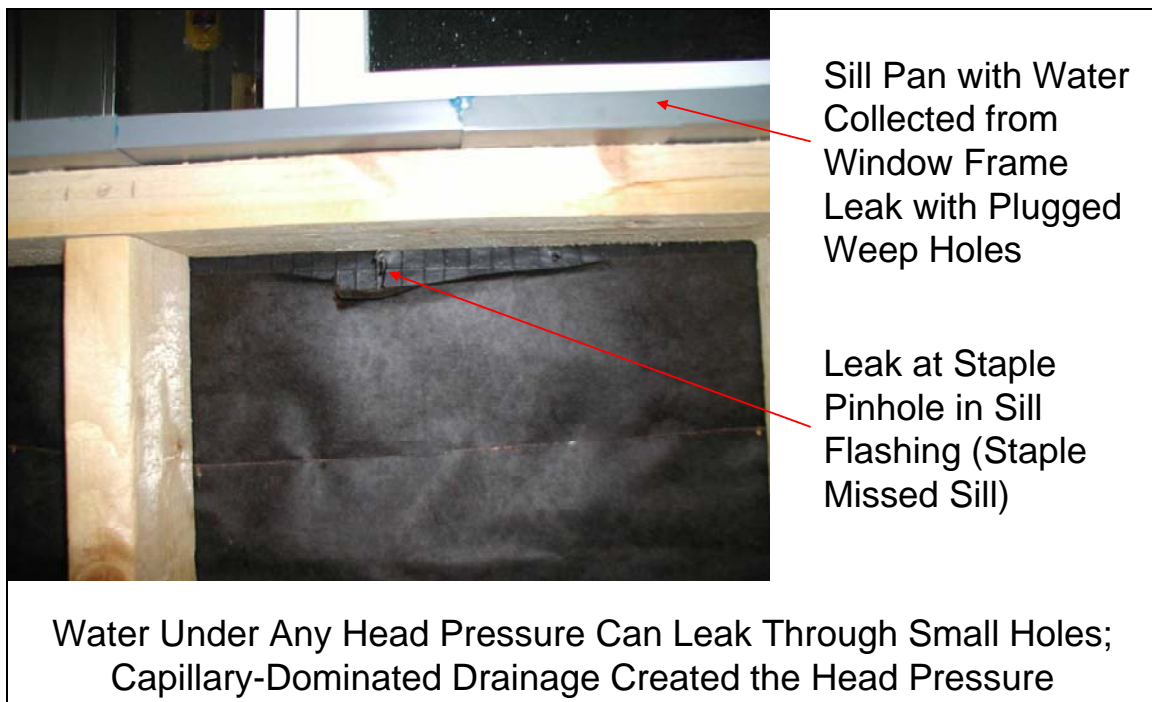


Figure 22. Leakage with sill pan and open frame construction

- Stucco with freshly caulked window frame prevented liquid water penetration at window/wall interface, even with reverse shingle-lap
- Stucco cladding with caulk stops bulk water flow.
- Capillary suction transports moisture to interior side of stucco.
- Low pressure expanding foam sealant (an air barrier) improved WRB performance at sill in some cases (Figure 23).
- Sealant contained leaks when full seal was achieved.
- Sealant did not contain leaks when misapplied or incompatible with substrate
- Perforated housewrap leaked through perforations with and without stucco cladding.
- No observable leaks occurred on interior side of OSB sheathing at window/wall interface.
- Leaks occurred when the moisture drainage mechanism was either liquid water or possibly capillary moisture flow after application of stucco cladding based on destructive disassembly (Figures 24 and 25).



Figure 23. Leak with foam sealant due to misapplication/incompatibility

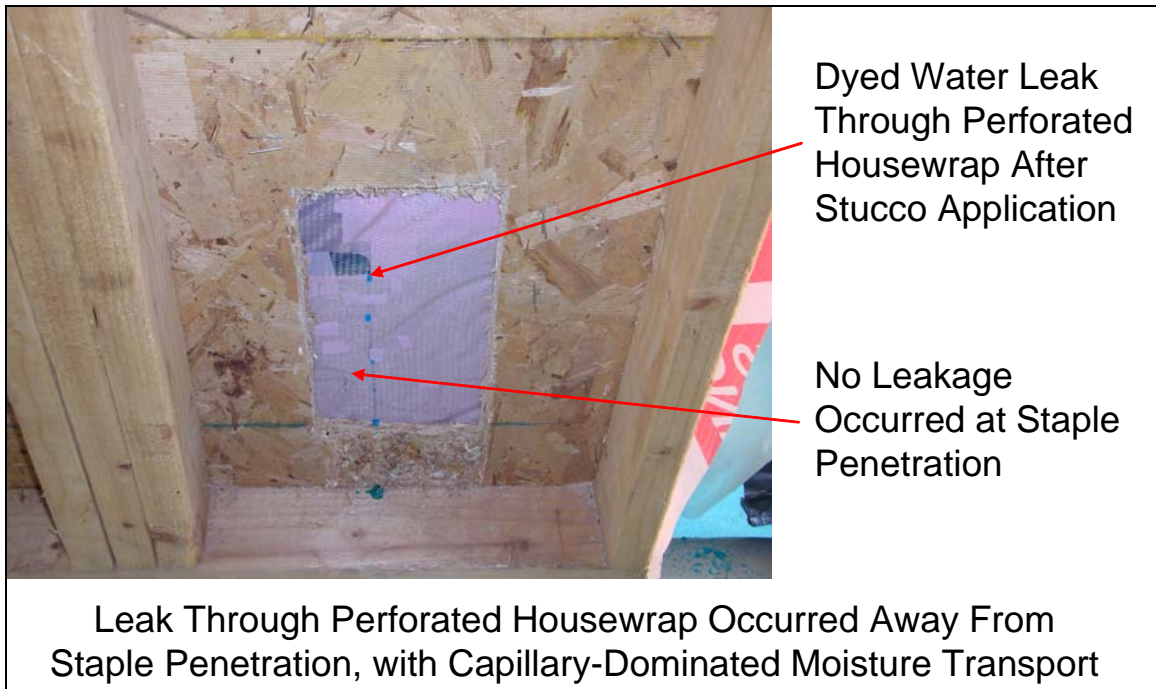


Figure 24. Leak through perforated housewrap during 15-minute blue dye spray test

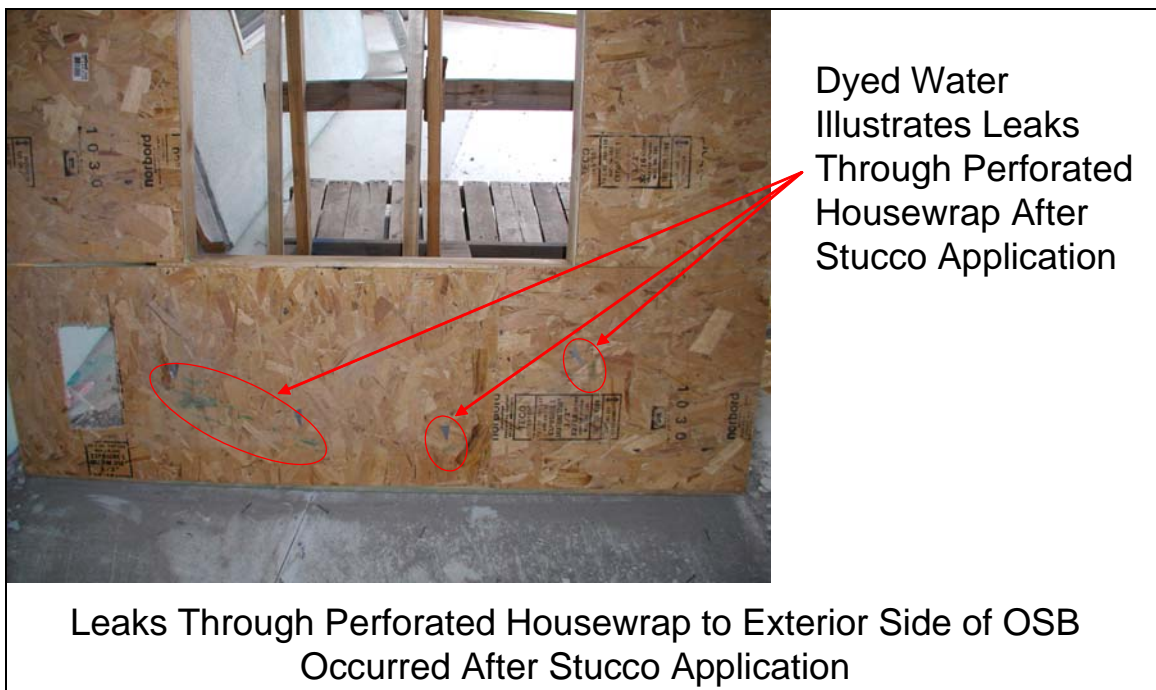


Figure 25. Leaks through perforated housewrap to OSB after stucco application

3.5.4. Conclusions and recommendations

Laboratory evaluations of the window/wall interface and WRBs support the following conclusions:

- A capillary break between stucco and WRB is required for optimal gravity drainage.
- Double layer provides space, outer layer provides bond break.
- Sill pan drains to interior layer (the functional WRB).
- Windows leak.
- Amount and location of leakage are unpredictable.
- Panned sill drainage system is essential.
- Full air barrier is required at all reveals.
- Consensus standards are needed.
- Performance and prescriptive, material and installation standards are needed.
- Standards must be realistic, supported by field data and validated models.

Data collected during this research project provided some support for the hypothesis that placing a sill pan flashing beneath vinyl windows as recommended by ASTM E2112-01R may reduce the risk of consequential water intrusion into wall cavities in as-built construction. Peer-reviewed field data on the performance of different WRB options and failure mechanisms of as-built window/wall assemblies for California new construction could not be found during this project. Anecdotal data and forensic evaluations provided helpful information, but did not establish authoritative links between various designs and long-term field performance as implemented. The protocols and targeted installation methods included in this project were intended to simulate bulk water intrusion on as-built construction realistically and to evaluate both design and construction factors related to bulk water drainage. However, there is no way to judge the true relevance of this work without field performance data and associated methods of test. As a result, project test results are considered informative, but not authoritative. Nonetheless, results, if credible, were sufficiently compelling to warrant further research and strongly support the need for field data collection. Results also provided technical support for recommending properly designed and installed WRBs to reduce the risk of bulk water intrusion and mold growth.

Disposition of laboratory results developed during this project will depend on which of the following scenarios is considered valid:

Scenario 1: Unacceptable Protocols

- The protocols were unacceptable because they did not align with current industry consensus standards and did not use appropriate methods or materials.
- Ignore project results, wait for appropriate protocols developed by consensus organizations such as ASTM to address legitimate research questions.

Scenario 2: Reasonable Protocols, but Poor Quality Implementation

- The protocols used reasonable methods and materials in the absence of industry consensus standards, but the implementation in the actual experiments was of poor quality. Better implementation would have shown more credible results.
- Ignore project results, and implement similar protocols with qualified staff and facilities to provide credible results.

Scenario 3: Reasonable Protocols Implemented Well, but with Questionable Relevance

- The protocols used reasonable methods and materials in the absence of industry consensus standards and generated credible results, but have questionable relevance to actual field experience. Protocols may be too severe or not targeted to relevant issues, and may contain numerous laboratory artifacts.
- Publish results for scientific value, but do not interpret them or make substantive recommendations. Results are likely to be misleading and could result in significant negative unintended consequences in the marketplace. Encourage further research on building science phenomena, and initiate major field data collection effort to identify underlying causes and consequences of moisture and mold problems. Continue development of consensus standards using best available methods and expertise in the absence of corroborating field data. Obtain feedback from relevant market participants regarding major effort to collect field data on targeted parameters based on expert judgments and appropriate field collection methods.

Scenario 4: Reasonable Protocols; Relevance is Unknown, but May Be Significant

- The protocols appear to have used reasonable methods and materials in the absence of industry consensus standards, and may have significant but unknown relevance to actual field experience.
- Publish results, provide information on potential market relevance, but avoid speculation as much as possible. Replicate at other laboratories, and validate results with field data. Encourage further research on building science phenomena, and initiate major field data collection effort to identify underlying causes and consequences of moisture and mold problems. Until field data are collected, results remain potentially misleading and could result in significant negative unintended consequences in the marketplace. Obtain feedback from relevant market participants regarding major effort to collect necessary field data on targeted parameters based on expert judgments and appropriate field collection methods.

Based on interactions with PAC members, building scientists, and participating manufacturers throughout the course of this project, Scenario 3 and Scenario 4 are considered the two most likely scenarios. Accordingly, research recommendations based on project results focus on two major initiatives:

- Develop and evaluate performance test methods for window installation methods as applied to wall assemblies

- Collect and analyze laboratory and field data on root causes and consequences of building envelope failures to identify and evaluate alternative mold risk reduction strategies for window/wall interfaces

The ASTM E 2112 standard committee recently formed a working group to explore options on fenestration installation performance test methods. Public and private stakeholder involvement in this process is strongly encouraged. Collaborative research efforts to evaluate candidate methods in laboratories and in the field are recommended.

The recommended field data collection and analysis program comprises a data collection effort involving laboratory experiments, laboratory house data collection and analysis, and targeted new homes representing a full cross-section of California construction and climate zones. The overall goal is to link moisture parameters with appropriate home construction parameters to enable authoritative root cause analysis of moisture and mold problems.

3.6. Hygrothermal Modeling of Building Wall Assemblies

3.6.1. Objective

The objective of the hygrothermal modeling task was to evaluate the hygrothermal performance of three stucco clad wall types, including conventional three-coat cement stuccos and a “one-coat” cement stucco (that was actually two-coat) constructions and a thin acrylic stucco-coated EIFS, in 16 climate zones in California.

3.6.2. Approach

The hygrothermal performance of three stucco clad wall systems was evaluated using the WUFI® Pro 4.0 building envelope simulation program and the METEONORM® 5.1 weather data generation program. The evaluation was completed first in detail for a single climate zone to establish a basis for a more focused and limited analysis then conducted on the balance of the 16 California climate zones. The OSB building layer was used to gauge the performance of the wall system, as it is vulnerable to both decay and mold problems. Using the WUFI modeling software, the moisture content of the OSB and its surface conditions of temperature and relative humidity were modeled.

WUFI Pro 4.0 is a public domain computer program that models one-dimensional water vapor diffusion between wall components and liquid water transport inside the building materials. It then calculates both the moisture content in the individual components of the wall systems and the psychrometric conditions at the wall component surfaces. The program was developed by Germany’s Fraunhofer Institute of Building Physics, which teamed with Oak Ridge National Laboratory (ORNL) to introduce the hygrothermal modeling tool to North America. The tool models the transient behavior of the wall system as it is exposed to hourly weather conditions, especially wind-driven rain. The modeling results display moisture content of wall materials indicating potential for organic decay, as well as surface temperature and relative humidity, indicating potential for mold formation. WUFI Pro 4.0 program is limited to one-dimensional water vapor diffusion between wall components and liquid water transport inside the building materials.

Wall systems studied included three-coat stucco (Wall 1), one-coat stucco (Wall 2), and EIFS wall system (Wall 3) with OSB sheathing, wall cavity insulation, and painted gypsum panel. For each wall system studied, the main variation was the type of building paper or housewrap that was used over the OSB sheathing. In Wall 1, two such layers were applied over the OSB sheathing with the outer layer always a typical building paper. Three options were available for the second layer: another layer of the typical building paper (3A), high permeance housewrap (3B), or low permeance housewrap (3C). In Wall 2 and Wall 3, only one layer of either building paper or housewrap was used.

METEONORM provided a cost effective and expeditious means to generate the necessary weather data files that are representative of the climate zones and are ready for use by WUFI. Even though the METEONORM hourly weather data sets are synthesized, this approach at least provides a transparent, consistent, and defensible methodology for creating the required 16 climate zone weather data files. Table 8 lists the climate zones used in this analysis, including their representative cities and key geographical data, along with a key weather parameter, the wind driven rain amount and dominant direction. The simulated wall systems were oriented toward the dominant wind driven rain direction.

Table 8. Climate zones used in this analysis

CZ	Representative City	County	Latitude	Longitude	Altitude (ft)	Precip (inches)	Wind Rain
1	Arcata	Humboldt	40.98	-124.10	216.5	36.83	S
2	Santa Rosa	Sonoma	38.52	-122.82	124.7	23.93	W
3	Oakland	Alameda	37.73	-122.22	9.8	20.93	W
4	Sunnyvale	Santa Clara	37.37	-122.03	102.0	19.95	SE
5	Santa Maria	Santa Barbara	34.90	-120.45	252.6	12.07	W
6	Los Angeles	Los Angeles	33.93	-118.40	105.0	12.07	W
7	San Diego	San Diego	32.73	-117.17	29.5	9.59	NW
8	El Toro	Orange	33.67	-117.73	380.9	11.36	SE
9	Pasadena	Los Angeles	34.09	-118.09	863.8	11.41	E
10	Riverside	Riverside	33.97	-117.33	1049.9	9.69	SE
11	Red Bluff	Tehama	40.15	-122.25	354.3	21.61	W
12	Sacramento	Sacramento	38.70	-121.58	23.0	17.85	E
13	Fresno	Fresno	36.77	-119.72	334.6	10.34	SE
14	China Lake	Kern/San Bernardino	35.68	-117.70	2230.0	5.58	SE
15	El Centro	Imperial	32.80	-115.67	13.1	1.69	SW
16	Mount Shasta	Siskiyou	41.32	-122.32	3543.3	16.96	S

Source: Gas Technology Institute

3.6.3. Outcomes

Results in California Climate Zone 16 (considered the most adverse climate zone for managing moisture) showed only a small reduction in moisture content in OSB sheathing as WRB permeance increased. The wall systems in 15 of the 16 Climate Zones showed little potential for OSB decay irrespective of wall construction or WRB option. Except for Climate Zone 1 (Arcata), only modest annual hours, if any, with OSB moisture content over 20% were exhibited by any of the wall systems (Figure 26).

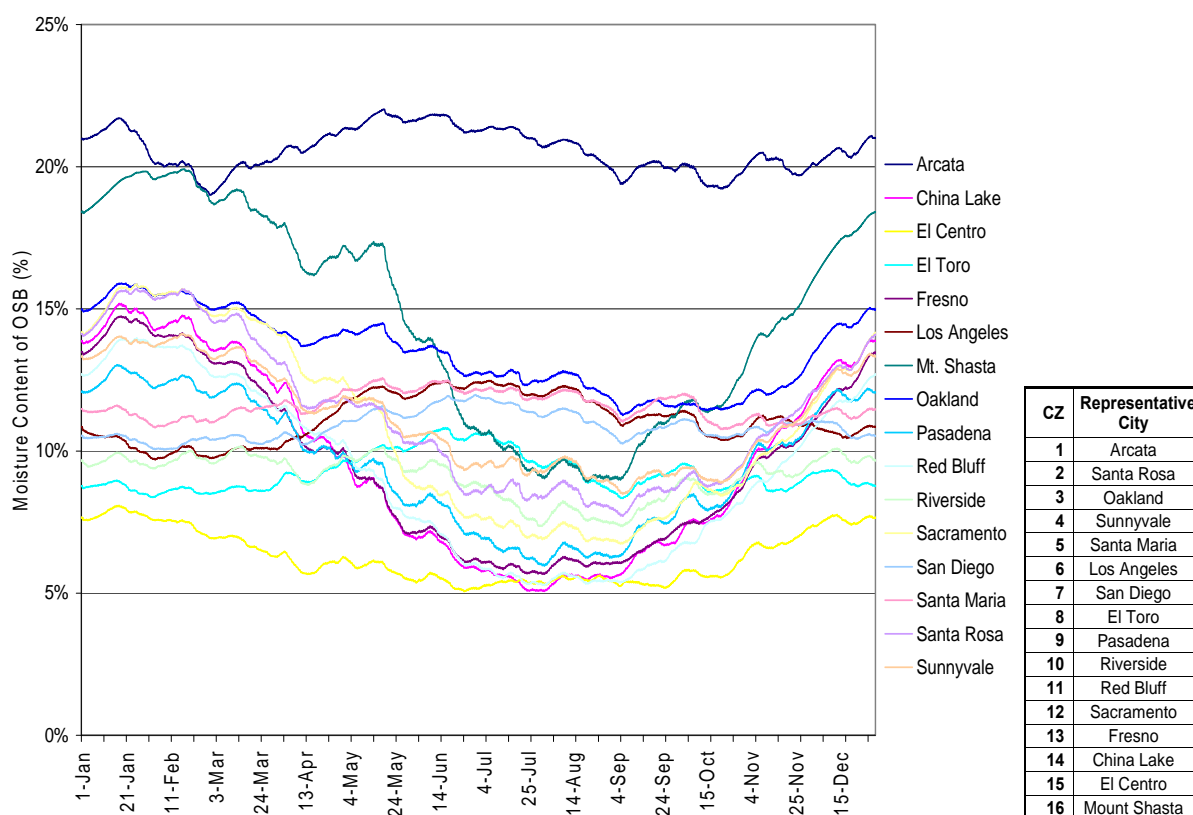


Figure 26. Percent moisture content of OSB in wall 1-3A4A5B in all 16 climate zones

Source: Gas Technology Institute

3.6.4. Conclusions and recommendations

The current one-dimensional water vapor diffusion and building material liquid water transport analysis capabilities of the public domain WUFI program used in this analysis provided useful information on wall drying rates for several California wall assemblies. However, further research is needed to encompass multi-dimensional analyses and other additional hygrothermal phenomena that can ultimately play a dominant role in wall system performance. These additional, potentially dominant effects, such as convective heat and moisture transfer and bulk water intrusion, are not yet in the public domain programs such as WUFI. ORNL has developed MOISTURE-EXPERT, an emerging multi-dimensional heat and moisture transfer research computer program with expanded hygrothermal modeling capabilities including:

- Bulk water penetration directly into wall system sublayers

- Sublayer surface drainage of bulk water out of the wall system
- Air movement over sublayers and into and out of wall system cavities

Literature published from ORNL MOISTURE-EXPERT research shows the dramatic effect on hygrothermal performance of varying levels of water penetration and drainage, as well as air movement, in stucco clad wall systems similar to those studied in this analysis. ORNL research shows a complex set of interactions in which water penetration can increase OSB moisture content twofold or more, while drainage and air movement can each decrease the OSB moisture content by a factor of two or more. The ORNL researchers note that such phenomena as water penetration, water drainage, and air movement could be directly related to design and construction issues, including the level of complexity or level of workmanship associated with making the wall air and water tight. This more complex hygrothermal modeling, coupled with field (or lab) measured and verified performance, is needed to gain a more thorough understanding of actual wall system moisture management issues.

3.7. Recommendations for Demonstration Homes

3.7.1. Objective

The objective of this task was to recommend mold resistant building systems and construction practices for use in the Task 4 demonstration homes based on results of the Task 2 situation analysis and Task 3 laboratory evaluations.

3.7.2. Approach

The project team reviewed candidate features identified and evaluated in Tasks 2 and 3 with participating builders based on criteria for selection developed in conjunction with the builders, project team members, PAC members, building scientists, participating manufacturers, and Energy Commission staff. Criteria included:

- Demonstrated efficacy
- Impact on energy consumption
- Incremental cost
- Schedule impact
- Code coverage
- Commercial availability
- Product manufacturer support
- Builder acceptance

Mold resistant construction is essentially a risk management problem. The goal is to minimize or eliminate conditions in the home that are conducive to mold growth. The builder may be able to reduce the risk of mold growth by controlling moisture or food sources using one or more of the following strategies:

- Keep liquid water out

- Keep water vapor out
- Get liquid water out
- Get water vapor out
- Tolerate liquid water
- Tolerate water vapor

Strategies 1 through 4 focus on moisture management. Strategies 5 and 6 focus on eliminating or chemically treating organic food sources. Solutions targeting one or more of these strategies were judged according to their expected impact on the risk of mold growth, along with any other consequences of use, either unintended or unavoidable.

3.7.3. Outcomes

Table 8 summarizes recommended materials and installation practices for the demonstration homes. John Laing Homes Inland Division planned on building at least four demonstration homes to permit evaluation of alternative materials or methods in each home. Clarum Homes planned on building one demonstration home using frame construction rather than the insulated concrete forms planned earlier. This increased the type and number of recommendations that can be implemented in the Clarum demonstration home.

Based on interactions with the two participating builders, all demonstration home recommendations were to be handled in the field without modifying architectural drawings and specifications or changing engineering reports. Builders agreed to coordinate with code inspectors, contractors, and product manufacturers to obtain the necessary materials and detailed installation instructions, integrate into construction schedules, and provide sufficient information for code compliance.

Table 9. Summary of recommendations for demonstration homes

Item	Mold Efficacy	Energy Impact	Cost Impact	Schedule Impact	Code Issues	Available in Market	Industry Support	Builder Accepted
ACI 302 Slab Vapor Retarder	Water, vapor	None	None	No	Check	Yes	Yes	Yes
Slab Seat at Door Sills	Water	None	Adds	No	Check	Yes	Yes	Yes
ASTM E2112-01 Method A1/ Sill Flashing	Water	None	Adds	Maybe	Check	Yes	Yes	Yes
Housewrap and Flashing	Water, vapor	Lower	Adds	Maybe	OK	Yes	Yes	Yes
Stucco Bond Break	Water	None	Adds	No	OK	Yes	Yes	Yes
Acrylic Stucco Coating	Water, vapor	None	Adds	Maybe	Check	Yes	Yes	Yes
Construction Drying	Water	Higher	Adds	Yes	OK	Yes	Yes	Yes
Demand Ventilation	Vapor	Lower	Adds	No	Check	Yes	Yes	Yes
Fungicide Coating	Food	None	Adds	Maybe	OK	Yes	Yes	Yes
Anti-Microbial Gypsum Panels	Food	None	Adds	No	OK	Yes	Yes	Yes
Cement Board in Bathrooms	Water, food	None	Adds	No	OK	Yes	Yes	Yes

Source: Gas Technology Institute

3.7.4. Conclusions and recommendations

The project team worked closely with the two participating builders and product manufacturers to identify and recommend mold resistant building assemblies and construction practices in addition to those already part of the builder's current designs. For field modifications, participating manufacturers committed to provide sufficient technical information and on-site support to ensure a successful installation and to provide incremental installed cost data. The final as built drawings will reflect field changes as required by the building officials.

4.0 Demonstration Homes

4.1. Background

The situation analysis (Task 2) identified a number of challenging mold problems facing California builders and recommend potential solutions for detailed laboratory evaluation and possible use in demonstration homes to be built by the two participating builders. Based on discussions with Energy Commission staff, the project team, PAC members, and building industry experts, the highest value areas for this project to address with laboratory testing were WRB design options around windows, concrete slab installation practices and materials (especially vapor retarder location and fill materials), and drying times for built-up wall assemblies.

Task 3 laboratory evaluations were designed to provide experimental evidence of moisture loading, propensity for mold formation, and potential performance improvements associated with innovative building assemblies and construction practices. These tests generated empirical data using existing and newly developed test protocols intended to permit replication by other testing organizations and to provide a technical basis for demonstration home design recommendations, builder guidelines, and future revisions to Title 24 energy efficiency standards. Based on the combined Task 2 and Task 3 results, the project team identified and recommended mold resistant building systems and construction practices that participating builders planned to use in the Task 4 demonstration homes.

The project team and participating manufacturers worked with the two participating builders, John Laing Homes Inland Division and Clarum Homes, during the demonstration home planning and construction period to incorporate recommended building assemblies and construction practices into seven production homes, six in Southern California, and one in Northern California. Both builders differentiate their companies as high quality, energy efficient builders. Clarum builds only Zero Energy Homes, and John Laing Homes Inland Division builds Energy Star® Homes. They have mature construction practices aligned with industry best practices, and each builder markets energy efficiency features to their customers.

4.2. Objectives

The objective of the demonstration homes effort was to demonstrate mold resistant assemblies and construction practices by building production homes containing recommended building components, assemblies, and construction techniques. Construction of the demonstration homes provided:

- Lessons learned based on actual construction practices
- Guidance on best practices for the builder's guide and training sessions
- Construction costs, potential cost savings, and builder benefits from improved construction techniques and materials

John Laing Homes Inland Division built a total of eight demonstration homes as a part of the Secret Garden development in Chino, California (Figure 27). Two included only modifications to the concrete slabs, and four included only modifications to the wall assemblies and selected

interior spaces. Two baseline concrete slab homes were also included to provide data on the impact of concrete slab installation procedures and materials on concrete slab performance and cost.

Clarum Homes built a single demonstration home as a part of the Pajaro Vista Zero Energy Home development in Watsonville, California (Figure 28). The home was joist construction on built-up foundation, and did not include any concrete slab construction features. It was predominantly open frame construction, and incorporated selected innovative assemblies that were compatible with Zero Energy Home construction materials and practices used by the builder.

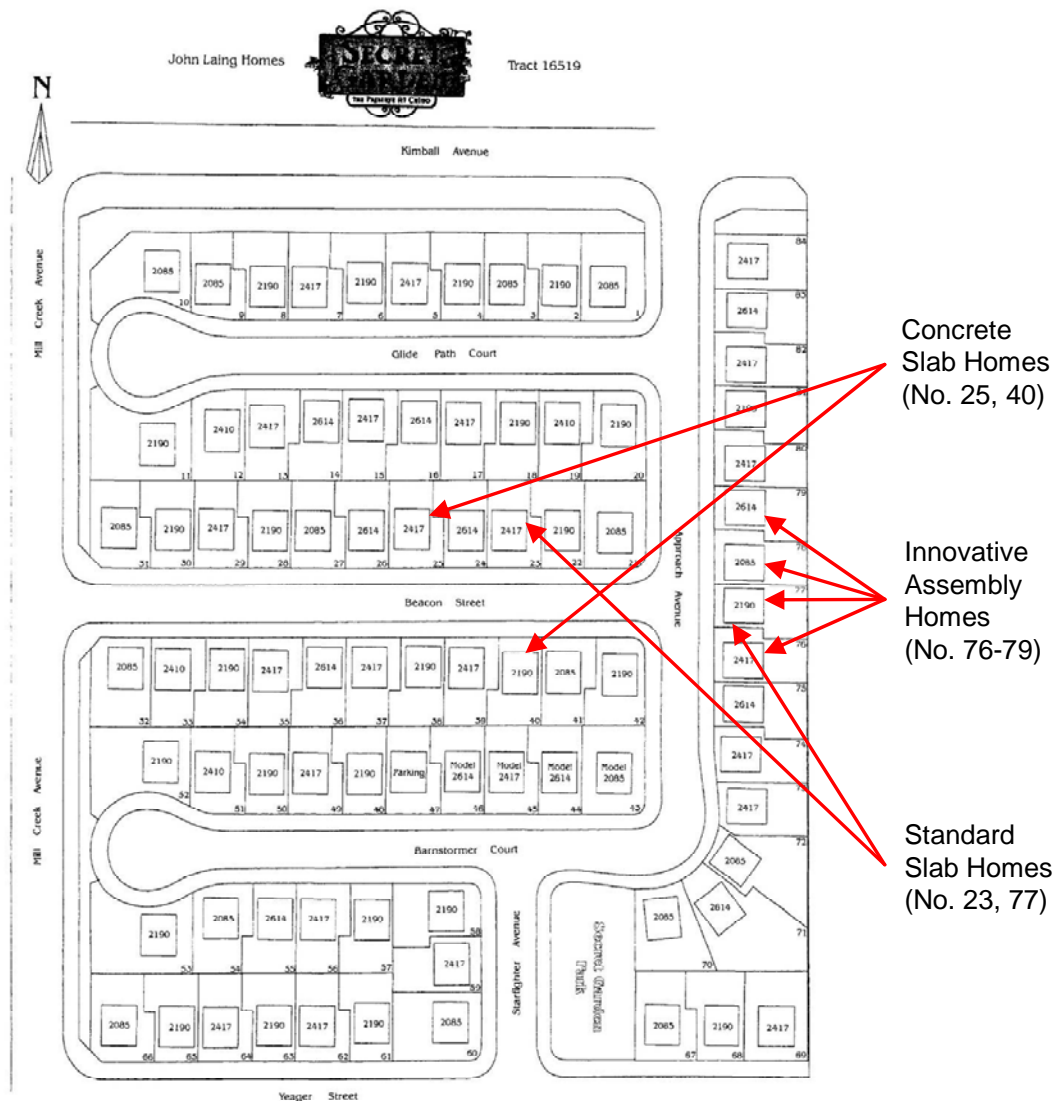


Figure 27. John Laing Homes Inland Division Secret Garden Development



Demonstration Home, Lot No. 24



4.3. John Laing Homes Concrete Slab Demonstration Homes

4.3.1. Objective

The objective of this effort was to support construction of two John Laing Homes Inland Division Concrete Slab Demonstration Homes in Southern California using materials and procedures contained in ACI 302.1R-04 “Guide for Concrete Floor and Slab Construction.”

4.3.2. Approach

Two concrete slab demonstration homes (Lot No. 25 and 40) were built and monitored as a part of the John Laing Homes Inland Division Secret Garden development in Chino, California. In addition, two similar homes with standard concrete installation practices (originally Lot No. 39 and 42, now Lot No. 23 and 77) are being monitored to help evaluate the impact of concrete slab installation procedures and materials on concrete slab performance.

For field modifications, participating manufacturers provided technical information and on-site support to ensure a successful installation and generate incremental installed cost data. Data acquisition system specifications for the concrete slab demonstration homes were developed by the project team in conjunction with co-funding non-contractual participants from the concrete industry.

Table 9 provides information on the materials and installation practices for the two John Laing Homes Inland Division Concrete Slab Demonstration Homes. The concrete slabs for these demonstration homes were installed in accordance with ACI 302.1R-04 “Guide for Concrete Floor and Slab Construction” on two homes with different floor plans and orientations (Lot No. 25 and 40). The ACI 302.1 method was compared to the builder’s standard practice on two baseline homes (Lot No. 39 and 42) with similar floor plans. The key differences between the two methods are vapor retarder permeance, and vapor retarder placement relative to the slab.

Table 10. Concrete Slab Demonstration Homes materials and contacts

Item	Purpose	Provider	Contact
ACI 302.1R-04	Installation guidelines for vapor retarder location, buffer materials, pouring, curing, and drying procedures and materials	Concrete industry consultants	Scott Tarr Peter Craig Claudia Lezell
Stego® Wrap 15 mil Class A	Low perm vapor retarder to address SB 800 liability provisions for slabs	Stego Industries	Bret Houck Matthew Blasdel
Confilm® EMACO® R320 CI Concresive® Paste LPL	Reduce evaporation rate Improved pocket form fillers for long-term corrosion protection	Degussa Construction Systems Americas	Robert Gulyas
HydraCure™	Reduce cracking during 7 day curing period	PNA Construction Technologies	Nigel Parkes Bob Waggoner
Rapid RH™ Relative Humidity Sensor	Long-term data acquisition	Wagner/CTL	Scott Tarr Lee Eliseian

4.3.3. Outcomes

Observations from the concrete slab demonstration home construction include the following:

- In the demonstration homes, vapor retarder was not applied under interior grade beams or exterior footings using the builder's conventional method (Figure 29), but rather was applied to provide full coverage (Figure 30).
- ACI 302.1-04R installation methods and materials increased the cost and labor content of slab installations (Figure 31). The key benefit of this installation method is reduced risk of mold growth from slab moisture. Long-term relative humidity data will be critical to assess the magnitude of this benefit.
- Slab cracks occurred as expected with the ACI 302.1-04R installation method (Figure 32), but not with the standard method in the Secret Garden development. The builder has had slab cracks in other developments, and viewed the demonstration home cracks as a tradeoff for the perceived moisture management benefits. Cracks were repaired as necessary before flooring was installed.
- A capillary break may not be required in many installations with Class A vapor retarders, but is typically a code requirement. Research is recommended in this area to explore technically justified cost reduction options for vapor retarder installation.
- Based on the experience gained in this project, the builder is implementing Class A vapor retarders in all future developments. They are also revising their post-tensioned slab designs to eliminate interior grade beams by using thicker slabs. This will enable them to provide full vapor retarder coverage under the slab more easily.

Long-term data acquisition is planned for the two concrete slab demonstration homes, as well as for two similar homes built with standard concrete installation practices, to evaluate the impact of concrete slab installation procedures and materials on concrete slab performance. Data collection for all four homes will be conducted using newly developed in situ relative humidity sensors (Figure 33). Relative humidity probes were inserted into four cored slab locations in each home on March 18, 2006. Long term monitoring for these four homes throughout 2006 will be provided by non-contractual concrete industry participants.



Figure 29. Ten mil vapor retarder installation below sand buffer, slab 39



a) Unrolling sheet

b) Fitting sheet to interior grade beam



c) Overlapped joints under grade beams, not taped



d) Taped slab joints



e) Mastic at plumbing and electrical penetrations



f) Post tension cables on chairs

Figure 30. Fifteen mil Stego® wrap installation sequence, slab 25



a) Interior grade beam and footings pour



b) Initial slab pour and leveling



c) Slab pour and tamping



d) Bull float



e) Supplemental bracing removed



f) Garage slab pour

Figure 31. Concrete pour, slab 25



Figure 32. Slab crack after post tensioning and enclosure, slab 25



Figure 33. Wagner Rapid RH TM, in situ relative humidity sensor

4.4. John Laing Homes Innovative Assemblies Demonstration Homes

4.4.1. Objective

The objective of this effort was to support construction of four John Laing Homes Inland Division Innovative Assemblies Demonstration Homes in Southern California. The builder used the design information provided by the project team and participating manufacturers and consultants to build the homes containing recommended assemblies with recommended construction practices. The project team also documented costs and recorded construction using videotapes and photographs as appropriate.

4.4.2. Approach

Four innovative assemblies demonstration homes, Lot No. 76 through 79, were built as a part of the Secret Garden development in Chino, California. The homes are frame construction with predominantly OSB exterior sheathing and wall cavity insulation. Wall cladding is three-coat stucco. For field modifications, participating manufacturers provided technical information and on-site support to ensure a successful installation and to provide incremental installed cost data. DAS specifications for the innovative demonstration home selected for long term monitoring (Lot No. 76) were developed by the project team in conjunction with Balanced Solutions, Inc., PAC members, and Energy Commission staff.

Table 10 provides information on the materials and installation practices for the four demonstration homes. Different housewrap options were used on each of the demonstration homes. In all housewrap installations, ASTM E 2112-01R Method A1 was used, with alternative sill pan flashing options installed. Caulking with backer rods was planned for installation around all windows. However, no caulking or backer rod was installed due to schedule constraints and stucco contractor preference. Dow Great Stuff™ Pro low pressure window and door foam sealant was applied to all window interior reveals.

Housewraps provided for the demonstration homes by participating manufacturers included DuPont Tyvek® HomeWrap™, Tyvek® StuccoWrap™ (5 foot roll) and DrainWrap™ (9 foot roll), and Dow Styrofoam® Weathermate Plus®. Double ply building paper was installed on Lot No. 79. This approach allowed comparison of installed cost, including materials, taping, labor, and trade coordination. Different window flashing systems were used, including Dupont™ FlexWrap™, Dupont™ StraightFlash™, Pella® SmartFlash™, Fortifiber Moistop® E-Z Seal®, Moistop® Corner Shield™, and FortiFlash® flashing.

Installation of SureSill™ sill pan flashing was attempted in one demonstration home, but due to dimensional interferences with the installed windows, a decision was made not to install this product in the demonstration home.

WD-40® bond break was sprayed on weep screeds on one demonstration home. The intent was to help liquid water drain more effectively at the weep screed/stucco interface. Installation method and materials were developed in conjunction with the Lath and Plaster Institute of Northern California.

Dri-Eaz intends to provide construction drying services to at least one additional demonstration home in 2006, but had not completed this effort by the time this report was prepared. Energy usage, schedule impacts, and site conditions will be monitored during the drying process to determine the benefits and costs, which will be reported separately to the participating builder by Dri-Eaz.

Foster® 42-42™ mold resistant sealer was applied to two of the demonstration homes on selected concealed shear walls and studs to evaluate the incremental cost and impact on construction schedule.

USG HUMITEK™ mold resistant gypsum panels were installed in the utility room and bathrooms of one demonstration home. The International Residential Code (IRC) no longer approves greenboard as a tile backer in wet areas and instead recommends cement-based backer boards or other moisture-resistant products. USG Fiberock® gypsum panels were installed in bath and shower areas of one demonstration home to compare their cost and ease of use to paper-faced greenboard previously used by the builder.

Table 11. John Laing inland division demonstration homes materials and contacts

Supplier	Product/Service	Contacts
Broan-Nutone LLC	Continuous duty bath fan/lights	Terry Pond, Kevin Morris
Dow Chemical	Housewrap, Tape, Foam Sealant, Engineering Support	Doug Bibee, Mel Rasco, Bob Braun
Dri-Eaz	Construction drying system, engineering support	Darren Hudema
DuPont Nonwovens	Housewrap, tape, flashing, engineering support	Theresa Weston, Brett Lubsen
Fortifiber Building Systems Group	Building paper, flashing, engineering support	David Olson
Foster Products	Fungicidal protective coating, engineering support	Troy Anderson
Pella Corporation	Flashing, engineering support	Cordell Burton
SureSill	Sill pan, engineering support	Mishko Teodorovich
Tamarack Technologies, Inc.	Ventilation fan controllers, engineering support	Paul Raymer
USG	Mold resistant gypsum panels, engineering support	Paul Shipp

Two of the demonstration homes incorporated demand ventilation strategies using Broan-Nutone LLC Model QTXE080FL continuous duty low sone fan/lights controlled by Tamarack

Humitrak™ AS dehumidistat or Airetrak™ timed controller in Bath 2 on the second floor. This strategy focused on the bathroom. In one home, the exhaust fan operated automatically whenever humidity conditions exceed the setpoint and in the other home, a timed ventilation strategy used. The incremental cost of this technology was evaluated, and homeowner acceptance will be assessed by the participating builder.

Concrete slab seats (¾-in deep) were designed into the footings at sliding doors and were intended to be installed in one demonstration home to determine the cost and installation issues associated with providing a back dam for door sills. However, due to construction schedules and coordination with the concrete slab installers, the seats were not installed in the demonstration homes at this site. Nonetheless, based on the design information provided in this project, the builder plans to use concrete slab seats in future production homes.

4.4.3. Outcomes

Innovative materials and installation practices in these homes focused on WRB options and construction sequence, window installation methods, mold resistant sealer and interior gypsum panels, construction drying services, and ventilation control and noise reduction strategies.

Observations from the innovative assemblies demonstration home construction include the following:

- The construction sequence evaluated for the housewrap demonstration homes included installing housewrap before windows and other penetrations were flashed (Figure 34). This sequence was intended to fully integrate self-adhered flashing to the housewrap, providing a continuously sealed WRB. This approach was consistent with manufacturers' installation instructions and recommendations by building science consultants on this project. However, because it is more expensive to implement and introduces different risks, this sequence is rarely used in California home construction with stucco cladding. Instead, all penetrations are typically installed and flashed with mechanically fastened flashing before the WRB is installed. The stucco contractor installs the entire WRB and cladding, including housewrap, associated flashing integration, building paper, lath, and stucco, after all flashing is installed by various trades. The typical sequence limits the need for trade coordination while reducing labor content compared to the sequence used in the demonstration homes. It also reduces the total number of staples and related risk of water intrusion behind the WRB.
- Sources of incremental cost and risk associated with application of the WRB before installing flashings and windows included:
 - Risk of reverse shingle-laps at penetrations
 - Trade coordination and education for construction sequence modifications
 - Incremental labor content
 - Risk of leaks at taped butt joints (e.g., holes, tears, v-cut for head flashing)
- Participating builders and contractors did not consider application of the WRB before installing flashings and windows to be cost-effective with stucco wall assemblies. While

both builders remain open to discussions about housewraps, at this time they intend to continue using double ply building paper for future developments with three-coat and one-coat stucco cladding.

- Window installation using ASTM E 2112-01R Method A1 and self-adhering flashing went smoothly once the window installation contractor was trained on the procedures (Figures 35 and 36). No substantive technical issues were identified. The key differences from the standard installation method were labor content and material cost.
- ASTM E 2112-01R window installation methods are intended to reduce the risk of moisture from window leaks while providing a durable installation, especially at the sill. Since these methods add both cost and time, the builder must make informed risk management decisions before deciding whether to use these options. Both builders are currently evaluating these flashing and installation approaches and may consider them in future developments.
- Total incremental material and labor cost per home with self-adhered flashing ranged from \$250 to \$700. Despite these increased costs, builder and manufacturer feedback indicates a strong and growing acceptance of self-adhered flashing in California based on perceived advantages over mechanically fastened flashing.
- Application of mold resistant sealer went smoothly and did not impact the remaining production schedule (Figure 37). Labor content associated with room preparation was a significant cost factor. Careful scheduling of the application that minimizes required taping and sealing (e.g., around tubs) would have a large impact on reducing application cost. The builder remains interested in pursuing this technology option for appropriate situations and will evaluate it as a part of their risk management strategy for future developments.
- Installation of mold resistant gypsum panels went smoothly and did not impact the production schedule. The incremental cost of the materials was the only significant difference from standard practice. The builder remains interested in pursuing this technology option for appropriate situations and will evaluate both materials as a part of their risk management strategy for future developments.
- Automated bathroom relative humidity control is challenging, but worth investigating as a benign control strategy (Figure 38). Its goal is to remove residual moisture automatically whenever needed and when the manual switch is off. Since the user may operate the exhaust fan manually when generating the moisture load (e.g., due to bath or shower), its incremental benefit is variable. Low noise, continuous duty fans are a key element of this strategy. Both builders perceive the low noise fans and relative humidity controller to have potential marketing benefits and plan to provide future feedback on the value they attach to this feature.
- Wood and OSB moisture content levels ranged from 10–13% throughout the monitoring period from December 14, 2005 through February 4, 2006. Dry weather conditions prevalent throughout the construction period appear to have permitted significant wood drying to occur prior to wall enclosure.

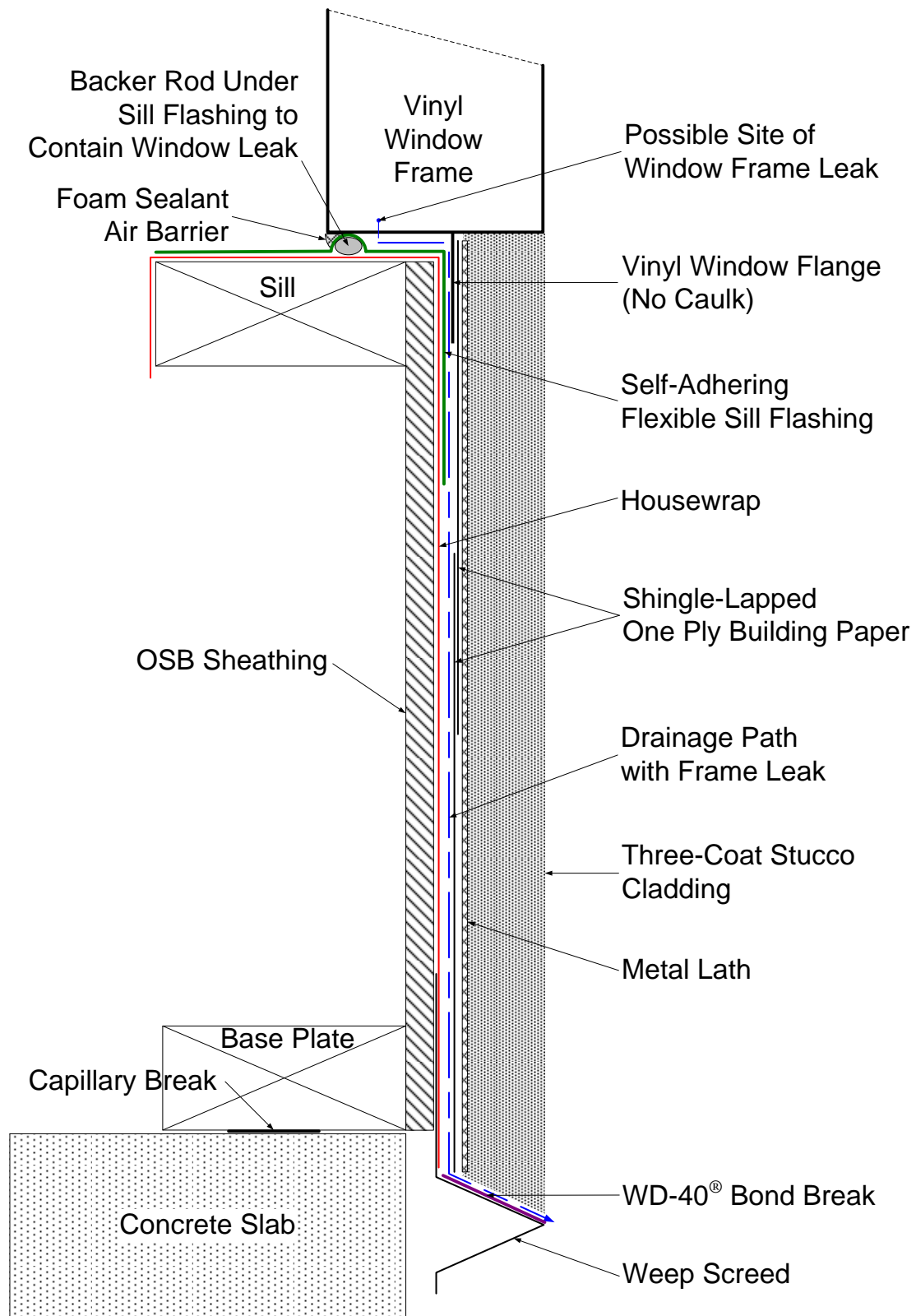


Figure 34. Housewrap/sill flashing schematic with drainage path



Figure 35. Window installation, ASTM E 2112-01R Method A1, Lot No. 76



Backer rod underneath FlashWrap™

Figure 36. Flexible sill flashing with $\frac{3}{8}$ -in backer rod backdam, Lot No. 78



Figure 37. Application of 42-42 in first living area, Lot No. 77



a) Model QTXE080FL fan/light



b) Airetrak™ timed controller

Figure 38. Continuous duty bath fan/light and timed controller installation, Lot No. 77

4.5. Clarum Homes Demonstration Home

4.5.1. Objective

The objective of this effort was to support construction of the Clarum Homes Demonstration Home in Northern California. The builder used the design information provided by the project team and participating manufacturers and consultants to build the homes containing

recommended assemblies and using recommended construction practices. The project team also documented costs and recorded construction using videotapes and photographs as appropriate.

4.5.2. Approach

One demonstration home, Lot No. 24, was built as a part of the Clarum Homes Pajaro Vista development in Watsonville, California. The home is predominantly open frame construction except at shear walls, which have OSB sheathing. Wall cladding is one-coat stucco with exterior insulation and additional wall cavity insulation. Participating manufacturers provided technical information and on-site support to ensure a successful installation and provide incremental installed cost data. Data acquisition system specifications for the demonstration home were developed by the project team in conjunction with project advisors and Energy Commission staff.

Table 11 provides information on the materials and installation practices for the Clarum Homes Demonstration Home. Housewrap selected for the demonstration home was DuPont Tyvek® StuccoWrap™ (5 foot roll) and DrainWrap™ (9 foot roll). This allowed comparison of installation experience with the other demonstration homes in Southern California, as well as with Clarum's standard construction materials and practices. Window flashing was Dupont™ FlexWrap™ and StraightFlash™. Window installation followed ASTM E 2112-01R Method A1. Caulking with backer rods was planned for installation around all windows, but was not installed due to builder preference. Dow Great Stuff™ Pro low pressure window and door foam sealant was applied to all window interior reveals.

USG HUMITEK™ mold resistant gypsum panels were installed in the utility room and bathrooms. USG Fiberock® gypsum panels were installed in bath and shower areas.

Broan-Nutone LLC Model QTXE080FL continuous duty low sone fan/light controlled by Tamarack Humitrak™AS dehumidistat were installed in both bathrooms and the laundry room. This strategy automatically operates the exhaust fan whenever humidity conditions exceed the setpoint. The incremental cost of this technology was evaluated, and homeowner acceptance will be assessed by the participating builder.

Table 12. Clarum demonstration home materials and contacts

Supplier	Product/Service	Contacts
Broan-Nutone LLC	Continuous duty bath fan/lights	Terry Pond, Kevin Morris
Dow Chemical	Foam sealant	Bob Braun
DuPont Nonwovens	Housewrap, tape, flashing	Marc Silveira
Tamarack Technologies, Inc.	Ventilation fan controllers	Paul Raymer
USG	Mold resistant gypsum panels	Paul Shipp

4.5.3. Outcomes

Experience with housewrap in this demonstration home was similar to that at the John Laing Inland Division homes. Open frame construction posed additional challenges for tape seals with DrainWrap™ (Figure 39). While taped seals are not considered critical elements of the WRB at seams or shingle-lapped penetrations, there may be some impact on air retarder performance. The only locations that require tape to seal fully for WRB functionality are at the v-cut joint extending beyond the head flashing. The risk of leaks through this cut should be minimal, but is worth consideration. Additional protection can be provided by shingle-lapping a second piece of tape along the seam.

Clarum remains open to discussions about housewraps based on the potential for further energy efficiency and durability, but at this time they intend to continue using double ply building paper for future developments with insulated one-coat stucco cladding.

Experience with window flashing in this demonstration home was similar to that at the John Laing Inland Division homes with identical flashing. An improved flanged vinyl backdam (versus backer rod) for this installation facilitated stapling to the sill. Reveals were adequate to accommodate the backdam, but reduced clearances for the foam sealant. The flashing material was able to withstand the leveling tool used by the window installer without damage (Figure 40). For sill pan installations, the contractor would have to use a different leveling method to avoid interference with the sill pan backdam.

Clarum is currently evaluating these flashing and installation approaches as a part of their quality and risk management strategy and may consider them in future developments.

Installation of mold resistant gypsum panels went smoothly and did not impact the production schedule. The incremental cost of the materials was the only significant difference. Clarum remains interested in pursuing this technology option for appropriate situations and will evaluate both materials as a part of their risk management strategy for future developments.

Installation of bath fan/lights and controls went smoothly and did not impact the production schedule. Clarum perceives the relative humidity controller to be a solution to a laundry area humidity control issue and plans to provide future feedback on the value they attach to this feature.

4.6. Demonstration Homes Conclusions and Recommendations

The demonstration home planning, construction, and monitoring tasks met all project goals and successfully implemented nearly all recommended assemblies and construction practices. Voluntary builder and manufacturer commitment, cooperation, and input were critical to the success of the demonstration homes tasks. Builder and manufacturer feedback to date indicates mutually beneficial value from their participation. Based on project results, builders and participating manufacturers have expressed willingness to participate in future demonstrations. Task 4 demonstration home results corroborated research needs identified during the Task 2 situation analysis and Task 3 laboratory evaluations.



Figure 39. Poor tape adhesion in open frame construction



Figure 40. Good compatibility between flexible sill flashing backdam and leveling tool

5.0 Information Product Dissemination

5.1. Background

Information gathered and developed during the course of this contract will have the greatest impact if it is widely available in the appropriate format. Publication options considered during this project included technical reports on Internet websites, presentations, and peer-reviewed technical papers at technical society meetings, publication in industry handbooks, and training materials and sessions. Additional options included oral presentations to standards committees on relevant topics and participation in ongoing standards initiatives.

5.2. Objectives

The objective of the Information Product Dissemination task was to disseminate the information products developed during the course of the project to the target customers, including builders, contractors, trade associations, government regulatory agencies, researchers, and consumers. Information products included:

- Builder's Guide
- Builder's Training Session Materials
- Title 24 Technical Data Report
- Presentations to Stakeholder Groups and at Technical Society Meetings

5.3. Builder's Guide

5.3.1. Objective

The objective of the Builder's Guide was to develop residential building guidelines on mold-resistant building components, assemblies, and construction practices. The guidelines included recommendations, supporting data, and references to other guideline information pertinent to mold-resistant construction. Where feasible and appropriate, drawings and specifications were included as a part of the guidelines.

The majority of the project tasks consisted of laboratory and field studies of building assemblies that are important to keeping building materials dry and therefore free of mold growth. The results of that research were published in other task reports. In addition to that work, the project team was charged with providing a report to the California Energy Commission to include not only the results of the research, but also the current understanding of experts about ways to prevent mold problems in new residential construction.

5.3.2. Approach

The Builder's Guide describes a three-part strategy to reduce mold risk. The strategy is based on an understanding of mold problems in California houses and how such problems can be avoided:

- Keep most of the water away from the house through a few critical landscaping and drainage decisions made by the developer, designer, builder, and owner

- Keep the rest of the water out by ensuring the roof, walls, and foundation shed and exclude water consistently, while draining it away from the house
- Limit mold growth while moisture dries out by stopping water leaks and spills from spreading indoors and by choosing materials and assemblies which are less prone to moisture retention or mold growth when challenged by occasional wetting.

The Builder's Guide consists of the opinions and judgments of a wide variety of experts. These go well beyond the specific topics researched during this project. The Builder's Guide is considered a good beginning rather than the last word on this highly complex topic. It's also useful to keep in mind that this report has no force of regulatory authority. It represents the judgments of the authors about what currently constitutes useful advice to developers, designers, builders, and owners about how to reduce the risk of mold growth in new California homes. The guide is arranged according to which party is likely to be making each decision and the timing of each decision.

5.3.3. Outcomes

The Guide includes a number of actions to implement the risk reduction strategy during each phase of the process. During the development phase, the guide includes recommendations on budgetary decisions:

- Site grading, paving, lot coverage, and drainage
- Offering xeriscape (dry landscaping)
- Extra care for developments with irrigated landscaping
- Dealing with the increased risk of zero setback lot-lines
- Roof line decisions that favor water-exclusion
- Progress payments that favor watertight connections
- Below-grade walls on hillsides that have greater risks for mold
- Budget decisions that can affect the building's ability to limit mold growth

During the design phase, the guide includes recommendations on materials and installation specifications:

- Architectural look-and-feel decisions that keep water away
- Fireproof roof overhangs for urban-wildlife interface zones
- Xeriscape that reduces annual water loads and risks
- Extra attention to houses with zero setback lot lines
- Kickout flashing wherever a sloping roof ends at a vertical wall
- Keeping liquid water and vapor out of concrete slab foundations
- Sealed, vapor-retarding ground covers for crawl spaces

- Two layers of building paper or housewrap between stucco and sheathing
- Handling expansion cracks between stucco and window frames
- Avoiding problems in homes with stucco cladding
- Integrating window flashing and sill pans with the water-resistive barrier
- The importance of air seals under windows
- Below-grade exterior walls on hillsides
- Breathable interior finish
- Location of vapor barriers
- Dehumidification strategies
- Sufficiently quiet exhaust fans to encourage occupant use
- Moisture-tolerant materials in showers and bathtub surrounds
- Designs for occasional water leaks and spills in kitchens, bathrooms, and laundry rooms
- Pans under washers and refrigerators

During the construction phase, the guide includes recommendations on proper methods of installing designed systems, including:

- Addressing landscaping and irrigation risks
- Dry storage for pre-purchased lumber and gypsum panels
- Avoiding both mold and cracks in foundation slabs
- Logical trade sequence to minimize leaks around windows
- Spraying lubricant on stucco weep screeds to aid water drainage
- Measuring moisture in wood framing before “rocking the walls”
- Measuring moisture in wall board before paint and cabinets
- Sequencing (and supervision) to ensure systems are built as designed
- Requiring documented plumbing pressure test
- Checking and setting the arc of irrigation spray heads
- Ensuring spray-on cellulose insulation is dry before covering with gypsum wall board
- Drying wet materials to keep the project on schedule
- Applying mold resistant sealer to gain drying time
- Deal with any mold that grows during construction

For homeowners, the guidelines include the following recommendations and observations on budgetary and maintenance decisions that reduce mold risk:

- Roof overhangs reduce the rain load and reduce electrical bills.
- Complex roofs are risky.
- Plants and irrigation near the foundation are risky.
- Adjust irrigation spray heads to keep water off the house.
- Xeriscape (dry landscaping) reduces mold risk.
- Keep gutters free of leaves and keep rain water away from foundation.
- Use highly-permeable paint for exterior stucco.
- Dry out carpets after cleaning.
- Don't disconnect the clothes dryer exhaust hose.
- Recognize that indoor plants evaporate moisture constantly.
- Use shower and kitchen exhaust fans.
- Know where the master water shut-off valve is located.
- Dry moist materials immediately.
- Avoid interior wall finishes that are vapor retarders.
- Avoid storing paper and fabric in damp locations.
- Condensation is a potential problem.
- If there are water stains indoors in a new home, call the builder.
- When in doubt, measure moisture content.

The guidelines also discuss managing tradeoffs and minimizing unintended consequences. The discussion includes a voluntary approach to identifying, researching, designing, and implementing solutions to important problems like mold. Recommended steps include:

- Identify the problem of interest and knowledge gaps about the problem and its causes
- Perform targeted research on potential solutions and related information
- Develop intellectual property to implement solutions and information for standards actions to educate the engineering community and qualify the solution
- Commercialize and improve solutions in the free market when there are no market disconnects (e.g., beneficiary doesn't or won't pay for the solution)
- For market disconnects, implement rational regulations that rely extensively on voluntary standards (e.g., American National Standards Institute [ANSI]) and associated technical justifications

5.3.4. Conclusions and recommendations

Houses in California face very different environmental factors (sun, wind, rain, soil, earthquakes, floods) than, for example, houses in the Southeast United States. For this reason, no single approach will work well in all situations. Still, houses in all environments face a number of common challenges during their lives, such as rain, landscape irrigation, groundwater, interior moisture loads, structural leaks, and plumbing leaks. Durable, affordable houses require the developer, designer, builder, and homeowner to make informed choices that always implement the most cost-effective solutions to common problems and to make intelligent tradeoffs that improve system performance for the unique challenges faced by each house in its specific location.

5.4. Builder's Training Sessions

5.4.1. Objective

The objective of the builder training sessions was to develop a training plan and conduct two builder training sessions, one in Northern California and one in Southern California.

5.4.2. Approach

Indoor Environmental Engineering developed training materials based primarily on information in the Builder's Guide. Additional material for background and special cases was developed from their company's background in this area as well as other mold prevention and remediation resources.

The participating utilities (PG&E and Sempra Utilities) provided the venues, audiovisual equipment, and announcements to prospective attendees. Two half-day builder training sessions were conducted in December 2005. Registration was limited to builders to the extent possible. Copies of the draft Builder's Guide were handed out at each session. Participant feedback on guide content and format was positive.

5.4.3. Outcomes

Training sessions were conducted at the Sempra Utilities Energy Resource Center in Downey, California, on December 13, 2005, and at the PG&E Stockton Training Center on December 15, 2005. Attendance at the Downey session was 48, of which nearly all were builders or affiliates. Stockton attendance was 9, all builders.

5.4.4. Conclusions and recommendations

Feedback from both sessions was uniformly positive. Continuing education credits were recommended to encourage attendance. Sempra Utilities is interested in future sessions in conjunction with other scheduled training either at the Energy Resource Center or at building industry events. PG&E is also interested in exploring appropriate future offerings integrated with their other builder training programs.

5.5. Title 24 Technical Data Dissemination

5.5.1. Objective

The objective of the Title 24 technical data dissemination effort was to publish relevant technical data that can be used by interested stakeholders to propose changes to provisions of California Title 24 energy efficiency standards. A second objective was to provide laboratory protocols and other relevant technical data developed under this project to standards organizations, builders, and other affected stakeholders.

Based on discussions with Energy Commission staff, the key focus of the Title 24 technical data effort was an analysis to investigate the technical and economic performance of alternative weather resistive barriers affected by the Title 24 air leakage reduction provision. The scope of the study focused on products used beneath stucco cladding and evaluated the technical basis for a 10 perm lower limit, including conducting the following tasks:

- Tabulate relevant statistics for WRBs commonly used in California residential construction
- Characterize the air leakage performance of qualifying products and products that do not qualify for the air leakage reduction credit
- Evaluate the relevance of the reduction provision in light of the requirement for mechanical ventilation when overall specific leakage area (SLA) is less than 3.0
- Analyze the technical basis for the 10 perm lower limit, including information from peer-reviewed technical publications, anecdotal information, and other sources as appropriate

5.5.2. Approach

The evaluation of the technical basis of the Title 24 air leakage reduction provision was conducted through a review of technical publications and direct correspondence with building science professionals, product manufacturers, and product sales specialists.

Relevant code requirements and related ASTM standard provisions were summarized. Product statistics were compiled from manufacturer's specifications for WRBs used in California residential construction, including information on air leakage performance, permeance, and installed cost. An installed cost case study was performed based on distributor survey data and estimated labor costs for single-layer and double-layer WRB options.

Alternative Title 24 compliance paths were analyzed to characterize the approaches to achieving an overall SLA less than 3.0 and the role of the SLA credit in achieving that level. Additional information was collected on the relevance of the credit in practice. Finally, the technical basis of the SLA reduction amount and the minimum perm limit to qualify for the credit were reviewed.

5.5.3. Outcomes

Key findings regarding the Title 24 SLA reduction credit are summarized below.

The 10 perm minimum requirement for the SLA credit was established by consensus to address potential moisture concerns associated with building tighter homes. In the absence of field data relating housewrap permance to installed performance, the justification for the specific value was based on the Committee's interest in maintaining drying capability equivalent to 5 perm building paper without taped joints. No peer-reviewed field evidence to date in California homes on causes of building failures has identified any linkage between WRB perm rating and widespread moisture problems.

Moisture loading from water penetration and air infiltration into wall cavities can be orders of magnitude higher than vapor diffusion flows. Without sufficient airtightness, low perm vapor retarders may have little effect on moisture movement into or out of the wall due to moisture flows from air movement through the wall cavity.

The SLA credit does not distinguish between E1677 Type I and Type II air retarding wraps, even though only Type I wraps are required to pass a water resistance test. This may be an oversight if the intent of the credit is to ensure acceptable performance as both an air retarder and water-resistive barrier.

Product data listed in this study showed no significant correlation between air leakage rate and water vapor permance. The SLA credit excludes WRB options that may provide equivalent or superior air leakage performance in California climates.

Double-layer WRBs with airspace for drainage are strongly recommended by building scientists. The lower installation cost of two-ply building paper provides a significant incentive for builders to use this option rather than double-layer options as long as it meets code requirements, even though it is not functionally equivalent to double-layer WRBs. Benefits of the SLA reduction credit by themselves may not be sufficient to offset this incentive for the builder, potentially reducing the market impact of the SLA reduction credit.

Since an SLA below 3.0 can only be claimed through optional diagnostic testing, there is no way to achieve a design level of tightness requiring mechanical ventilation by claiming the default SLA reduction credit. Without diagnostic testing, homes that actually have an SLA below 3.0 as constructed with air retarding wraps may not be required to incorporate mechanical ventilation.

5.5.4. *Conclusions and recommendations*

This research effort was not able to identify any peer-reviewed field data or other technical studies that support or refute a specific perm limit in walls with stucco cladding in California homes. The current limit in Title 24 reflects consensus engineering judgment and risk management decisions in the absence of authoritative technical data.

Further research is needed to develop and evaluate laboratory and field performance test methods for integrated cladding and wall assemblies through voluntary standards development processes such as ASTM. The test methods should be realistic and relevant, supported by field data and validated models.

5.6. Assessment of Project Benefits and Future Initiatives

The objective of this effort was to assess the benefits provided by this research project, and provide a list of future opportunities and research recommendations. Project benefits should be

quantified when appropriate and feasible. Also, the assessment should include a realistic discussion of factors influencing market penetration for research products.

Future opportunities and research needs should focus on initiatives with potential value to California electric ratepayers.

5.6.1. *Benefits to California*

Benefits to California electric ratepayers that may accrue as a result of this project include qualitative and quantitative benefits in three different categories:

- Improved indoor environmental conditions
- Cost savings
- Energy efficiency

Participating builders have begun to incorporate into their production homes several strategies to reduce the risk of mold formation and growth based at least in part on recommendations in this project. Specific changes cited in feedback forms include:

- Self-adhering flashing
- Sill pans under windows
- Concrete slab seats under doors
- Class A vapor retarder
- Thicker slab instead of interior grade beams
- Low noise energy efficient bath exhaust fan/lights
- Mold-resistant coatings on OSB and studs in selected areas
- Quality inspection service

Each of these strategies will improve indoor environmental conditions and reduce risk of building failures. A synergistic benefit of this focus on quality will be improved energy efficiency. Envelope details, especially around windows, are critical for as-built construction to perform as designed. While it is difficult to quantify the energy impact of these quality improvements, they are real and may be quite significant.

The research results of the Title 24 investigation in this project have illustrated an opportunity to increase the market impact of energy efficient air retarding wraps through future revisions to the standard that provide appropriate builder incentives. Builders liked housewraps, but consider them too expensive. They prefer the convenience and familiarity of two-ply building paper. Each incremental home constructed with improved air barrier performance would reduce overall home energy consumption by 2% or more according to compliance software calculations. Further encouragement to use field verification instead of default credits would also increase market impact of this credit.

5.6.2. Future Initiatives

Research recommendations based on cumulative project results focus on three major initiatives:

- Expand field demonstration and monitoring of materials and methods with acknowledged energy efficiency, risk reduction, and performance benefits selected for full-scale implementation or further evaluation by builders under this project
- Develop and evaluate laboratory and field performance test methods for wall penetrations integrated with cladding and wall assemblies
- Collect and analyze laboratory and field data on root causes and consequences of building envelope failures to identify and evaluate alternative mold risk reduction strategies for window/wall interfaces

Recommended field demonstration and monitoring efforts include:

- Continue long term slab and moisture data acquisition initiated under this project
- Expand field demonstration and monitoring of ACI 302.1R-04 concrete slab installation methods and materials throughout California
- Alternative interior grade beam designs
- Exterior footing vapor retarder and waterproofing application solutions
- Optimized concrete mix strategies
- Additional climatic conditions
- Additional soil conditions

Collect comprehensive field data on window flashing and water resistive barrier performance and energy impact with stucco cladding throughout California.

- Alternative water resistive barrier options and installation sequences
- Sill pan flashing designs integrated with window installation methods and two-ply and two-layer water resistive barrier design options
- Window and stool compatibility
- Backdam designs
- Foam sealant air barrier effect
- Interior reveal designs to integrate air barrier with water resistive barrier
- Evaluate mold resistant sealer and gypsum panel cost and efficacy over time as a part of a comprehensive mold risk reduction strategy.

The ASTM E 2112 standard committee recently formed a working group to explore options on fenestration installation performance test methods. Public and private stakeholder involvement in this process is strongly encouraged. Collaborative research efforts to evaluate candidate methods in laboratories and in the field are recommended.

The root cause field data collection and analysis program comprises a data collection effort involving laboratory experiments, laboratory house data collection and analysis, and targeted new homes representing a full cross section of California construction and climate zones. The overall goal is to link moisture parameters with appropriate home construction parameters to enable authoritative root cause analysis of moisture and mold problems. Only by understanding these relationships can the building community move from the current status of experience-based “building art” to data-based “building science” and provide robust solutions to important problems.

6.0 References

- AAMA 711-05: *Voluntary Specification for Self-Adhering Flashing Used for Installation of Exterior Wall Fenestration Products*. 2005. American Architectural Manufacturers Association, Schaumburg, IL. www.aamanet.org.
- ACI 302.1R-04 - *Guide for Concrete Floor & Slab Construction* (PDF) Portland Cement Association, Skokie IL. www.cement.org.
- Assessment, Remediation and Post-Remediation Verification of Mold in Buildings. Guideline 2 – 2004*. 2004. American Industrial Hygiene Association, Fairfax, VA. www.aiha.org.
- ASTM Standard E2112: *Standard Practice for Installation of Exterior Windows, Doors and Skylights*. ASTM International, Philadelphia, PA. www.astm.org.
- Bailey, Holly. 2005. *Fungal Contamination: A Manual for Investigation, Remediation & Control*. Building Environment Consultants, Jupiter, FL. www.becif.com.
- Closed Crawl Spaces: A Quick Reference Guide*, 2006. (PDF) Architectural Energy Corporation. Raleigh, NC. <http://crawlspaces.org/>.
- Construction Quality Survey*. 2003. Criterium Engineers, Portland, ME. www.criterium-engineers.com
- Damp Indoor Spaces and Human Health*. 2004. National Academy of Medicine, Washington, D.C. www.iom.edu.
- Drying and Control of Moisture Content and Dimensional Change - Chapter 12, *The Wood Handbook*. 1999. U.S. Department of Agriculture Forest Products Laboratory, Madison, WI. www.fpl.fs.fed.us.
- Guidelines for on-site measurement of moisture in wood building materials*. 2001. Canadian Mortgage and Housing Corporation, Ottawa, ONT, Canada. www.cmhc-schl.gc.ca.
- The Gypsum Construction Handbook (Centennial Edition)*. 2000. USG Corporation. Chicago, IL. www.USG.com.
- Hagstrom, Carl. Flashing a Flanged Window. 2005. *Journal of Light Construction*, June 2005. Williston, VT. www.jlconline.com
- Henderson, Hugh I. 1998. The impact of part-load air conditioner operation on dehumidification performance. *Proceedings of the 1998 Indoor Air Quality Symposium*. ASHRAE. Atlanta, GA. www.ashrae.org.
- Humidity Control Design Guide*. 2006. Harriman, Brundrett & Kittler. ASHRAE, Atlanta, GA. www.ashrae.org.
- International Residential Code, 2004 supplement. Section R 703.6.3*. International Code Council, Falls Church, VA. www.iccsafe.org.
- Is Your Home Protected From Water Damage?* 2002. Institute for Business & Home Safety, Tampa, FL. www.ibhs.org.

Kanare, Howard. 2005. *Concrete Floors and Moisture*. Portland Cement Association, Skokie IL. www.cement.org.

Kerr, Dale. 2002. *Keeping Walls Dry*. Canadian Mortgage and Housing Corporation, Ottawa, ONT, Canada. www.cmhc-schl.gc.ca.

Lstiburek, Joseph. Water-Managed Wall Systems. 2003. *Journal of Light Construction*, March, 2003. Williston, VT. www.jlconline.com.

Lstiburek, Joseph. *Water Management Guide*. 2004. Building Science Press. Westford, MA. www.buildingsciencepress.com.

Lstiburek, Joseph. 2005. Why Stucco Walls Got Wet. *Journal of Light Construction*. July 2005. Williston, VT www.jlconline.com.

Managing the Risk of Mold in the Construction of Buildings. 2003. Mold Litigation Task Force of the Associated General Contractors of America. Arlington, VA. www.agc.org.

McCoy, Dennis. 2003. "A Close Look at Stucco," *Journal of Light Construction*, September 2003. Williston, VT. www.jlconline.com.

Moisture-Resistant Homes: A Best Practice Guide and Plan Review Tool for Builders & Designers. 2006. Newport Partners. U.S. Department of Housing & Urban Development Office of Policy Development & Research, Washington, DC. www.huduser.org/about/pdrabout.html.

Mold Remediation in Schools and Commercial Buildings. 2001. U.S. Environmental Protection Agency, Indoor Environments Division. Washington, D.C. www.epa.gov/mold/mold_remediation.html.

Preventing Losses From Moisture and Mold During Construction. 2003. Chelsea Group. Foundation of the Wall & Ceiling Industry, Falls Church, VA. www.awci.org.

Recommendations for the Prevention of Water Intrusion and Mold Infestation in Residential Construction. 2003. Lstiburek & Brennan. Texas Assn. of Builders, Austin, TX. www.texasbuilders.org.

Rose, William. *Water in Buildings: An Architect's Guide to Moisture & Mold*. 2005., John Wiley & Sons. Hoboken, NJ. www.wiley.com

S520 Mold Remediation Standard. 2006. The Institute of Inspection, Cleaning and Restoration Certification, Vancouver, WA. www.iicrc.org/s520info.html.

Staube, John and Eric Burnett. 2005. *Building Science for Building Enclosures*. Building Science Press, Westford, MA. www.buildingsciencepress.com.

Treschel, Heinz, Ed. *Moisture Analysis and Condensation Control in Building Envelopes*. 2001. ASTM International, Philadelphia, PA. www.astm.org.

Understanding Wood (Revised Edition). 2000. R. Bruce Hoadley. Taunton Press, Newtown, CT. www.taunton.com

The Wood Handbook. 1999. U.S. Department of Agriculture Forest Products Laboratory. Madison, WI. www.fpl.fs.fed.us.

7.0 Glossary

ACI	American Concrete Institute
ANSI	American National Standards Institute
ASHREA	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASTM	American Society for Testing and Materials
CDF	California Department of Finance
CDI	California Department of Insurance
DAS	data acquisition system
EIFS	exterior insulation finish system
Energy Commission	California Energy Commission
feet, foot	ft
GPM	gallons per minute
GTI	Gas Technology Institute
in	inch
IRC	International Residential Code
mil	millimeter
OA	outside air
ORNL	Oak Ridge National Laboratory
OSB	oriented strand board
PAC	Project Advisory Committee
PG&E	Pacific Gas and Electric
PIER	Public Interest Energy Research
psi	pounds per square inch
RD&D	research, development, and demonstration
SLA	specific leakage area

TDI	Texas Department of Insurance
UIC-ERC	Energy Resources Center at University Of Illinois At Chicago
USCB	U.S. Census Bureau
USG	U.S. Gypsum
WRB	water-resistive barrier

8.0 List of Attachments

Title	Report Number
Literature Review Summary Report	CEC-500-2007-035-AT1
Water Damage Claim Database Manual	CEC-500-2007-035-AT2
Candidate Building Assemblies and Construction Practices Report	CEC-500-2007-035-AT3
Laboratory Evaluation Test Plan	CEC-500-2007-035-AT4
Building Assemblies Laboratory Evaluation Results Report	CEC-500-2007-035-AT5
Concrete Slab Construction Practices Experiment Results Report	CEC-500-2007-035-AT6
Hygrothermal Modeling of Building Wall Assemblies Report	CEC-500-2007-035-AT7
Window Installation Methods Test Results Report	CEC-500-2007-035-AT8
Innovative Assemblies Demonstration Homes Plan Report	CEC-500-2007-035-AT9
Concrete Slab Demonstration Homes Plan Report	CEC-500-2007-035-AT10
Demonstration Homes Summary Report	CEC-500-2007-035-AT11
A California Builder's Guide to Reducing Mold Risk	CEC-500-2007-035-AT12
Mold-Resistant Construction Training Materials	CEC-500-2007-035-AT13
Impact of Title 24 Residential Air Leakage Reduction Credit on Water-Resistive Barriers in California Homes	CEC-500-2007-035-AT14
Benefits Assessment and Future Initiatives Report	CEC-500-2007-035-AT15